

PATENT ABSTRACTS OF JAPAN

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(54) MOTION ESTIMATING METHOD WITH MOTION PRECISION HAVING
ADAPTABILITY

(57)Abstract:

PROBLEM TO BE SOLVED: To provide a motion estimate method, with motion precision having adaptability that includes at least a technology for a motion vector with high pixel precision and less increase in the calculation quantity.

SOLUTION: One technology employs a fast search strategy in a partial pixel space, to smartly retrieve an optimum motion vector. Other technology uses a different interpolation filter in a different stage, to estimate a motion vector with high precision, so as to reduce the complexity of calculation. Still another technology employs rate distortion criterion applied according to a different motion precision, to decide both an optimum motion vector and the optimum motion precision. Furthermore, yet another technology uses a VLC table interpreted differently in a different coding unit, according to the related motion vector accuracy.

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CLAIMS

[Claim(s)]

[Claim 1] By finding out the optimal motion vector to one macro block It is the search approach with motion precision with the fast search adaptability for presuming the motion vector in motion compensation animation coding (a). In order to find out the optimal motion vector V2 Step which searches the 1st set of the motion vector candidate of centering on V1 square within the limits defined beforehand on a partial pixel resolution grid (b) In order to find out the optimal motion vector V3 Step which searches the 2nd set of the motion vector candidate of centering on V2 square within the limits defined beforehand on a partial pixel resolution grid (c) In order to find out said optimal motion vector of said macro block The search approach with motion precision with the fast search adaptability for presuming the motion vector characterized by changing including the step which searches the 3rd set of the motion vector candidate of centering on V3 square within the limits defined beforehand on a partial pixel resolution grid.

[Claim 2] In order to find out the optimal motion vector V2, said step which searches the set [1st] motion vector candidate of centering on V1 square within the limits defined beforehand on a partial pixel resolution grid In order to find out the optimal motion vector V2 The search approach with motion precision with the fast search adaptability for presuming the motion vector according to claim 1 characterized by including further the step which searches the 1st set of eight motion vector candidates in the square range 1 centering on V1 on a 1/2-pixel resolution grid.

[Claim 3] In order to find out the optimal motion vector V3, said step which searches the set [2nd] motion vector candidate of centering on V2 square within the limits defined beforehand on a partial pixel resolution grid In order to find out the optimal motion vector V3 The search approach with motion precision with the fast search adaptability for presuming the motion vector according to claim 1 characterized by

including further the step which searches the 2nd set of eight motion vector candidates in the square range 1 centering on V2 on a 1/6-pixel resolution grid.

[Claim 4] The search approach with motion precision with the fast search adaptability for presuming the motion vector according to claim 1 characterized by including further the step which uses V2 as a motion vector to said block when V2 has the minimum rate distortion cost, and the step which skips the step (c) of claim 1.

[Claim 5] In order to find out said optimal motion vector of said macro block Said step which searches the set [3rd] motion vector candidate of centering on V3 square within the limits defined beforehand on a partial pixel resolution grid In order to find out said optimal motion vector of said macro block The search approach with motion precision with the fast search adaptability for presuming the motion vector according to claim 1 characterized by including further the step which searches the 3rd set of eight motion vector candidates in the square range 1 centering on V3 on a 1/6-pixel resolution grid.

[Claim 6] In order to find out said optimal motion vector of said macro block Said step which searches the set [3rd] motion vector candidate of centering on V3 square within the limits defined beforehand on a partial pixel resolution grid The search approach with motion precision with the fast search adaptability for presuming the motion vector according to claim 1 characterized by including further the step which skips the candidate [finishing / test / already] in said set [3rd] motion vector candidate.

[Claim 7] Said step which searches said set [1st] motion vector candidate The step which searches said set [1st] motion vector candidate using the 1st filter in order to perform 1st interpolation is included further. Said step which searches said set [2nd] motion vector candidate The step which searches said set [2nd] motion vector candidate using the 2nd filter in order to perform 2nd interpolation is included further. Said step which searches said set [3rd] motion vector candidate The search approach with motion precision with the fast search adaptability for presuming the motion vector according to claim 1 characterized by including further the step which searches said set [3rd] motion vector candidate using the 3rd filter in order to perform 3rd interpolation.

[Claim 8] In order to find out the optimal motion vector V3, said step which searches the set [2nd] motion vector candidate of centering on V2 square within the limits defined beforehand on a partial pixel resolution grid (a) The step which searches 1 / 2 pel location which has the minimum RD cost next with three candidates V2 of 1 / 3 pel precision when there is V2 at the core, (b) When V2 is the vector of a corner Step

which searches 4 vector candidates of $1/3$ pel precision nearest to V2 (c) When V2 is between two corner vectors A corner with lower RD cost in two corners is determined. The search approach with motion precision with the fast search adaptability for presuming the motion vector according to claim 1 characterized by including further the step which searches 4 vector candidates of $1/3$ pel precision nearest to Rhine between said corners with lower RD cost.

[Claim 9] By finding out the optimal motion vector to one macro block It is the search approach with an adaptable motion precision for presuming the motion vector in motion compensation animation coding (a). In order to find out the optimal motion vector V2 using the 1st filter for performing the 1st interpolation Step which searches the set [1st] motion vector candidate in the grid centering on V1 (b) In order to find out the optimal motion vector V3 using the 2nd filter for performing the 2nd interpolation Step which searches the set [2nd] motion vector candidate in the grid centering on V2 (c) In order to find out said optimal motion vector of said macro block using the 3rd filter for performing the 3rd interpolation The search approach with an adaptable motion precision for presuming the motion vector characterized by turning to V3 including the step which searches the set [3rd] motion vector candidate in the grid which has a core.

[Claim 10] Said step searched using the 1st filter for performing the 1st interpolation is the search approach with an adaptable motion precision for presuming the motion vector according to claim 9 characterized by including further use of the easy filter for performing coarse interpolation.

[Claim 11] Said step which searches using the 2nd filter for performing the 2nd interpolation, including further use of an easy filter for said step searched using the 1st filter for performing the 1st interpolation to perform coarse interpolation is the search approach with an adaptable motion precision for presuming the motion vector according to claim 9 characterized by to include further use of the composite filter for performing fine interpolation.

[Claim 12] Said step searched using the 3rd filter for performing the 3rd interpolation is the search approach with an adaptable motion precision for presuming the motion vector according to claim 11 characterized by including further use of the composite filter for performing fine interpolation.

[Claim 13] Said step searched using the 1st filter for performing the 1st interpolation is the search approach with an adaptable motion precision for presuming the motion vector according to claim 9 characterized by including further use of the congruence linearity filter for interpolating the reference frame of 2×2 .

[Claim 14] Said step searched using the 1st filter for performing the 1st interpolation
Said step searched using the 2nd filter for performing the 2nd interpolation, including use of a congruence linearity filter further in order to interpolate the reference frame of 2x2 The search approach with an adaptable motion precision for presuming the motion vector according to claim 9 characterized by including further use of the cube filter for performing fine interpolation.

[Claim 15] Said step searched using the 3rd filter for performing the 3rd interpolation is the search approach with an adaptable motion precision for presuming the motion vector according to claim 14 characterized by including further use of the cube filter for performing fine interpolation.

[Claim 16] By finding out the optimal motion vector to one macro block In the search approach with an adaptable motion precision for presuming the motion vector in motion compensation animation coding (a) The step which searches the 1st [to the 1st optimal motion vector of said macro block] motion precision, (b) Said 1st optimal motion vector and step which encodes said 1st motion precision (c) The step which searches 2nd at least one optimal motion vector of said macro block in 2nd at least one motion precision, (d) The step which encodes said 2nd at least one optimal motion vector and said 2nd at least one motion precision, (e) The search approach with an adaptable motion precision for presuming the motion vector characterized by changing including said 1st [the] and the step which chooses said optimal motion vector using a rate distortion criterion from at least one optimal motion vectors.

[Claim 17] It is the search approach with an adaptable motion precision for presuming the motion vector according to claim 16 characterized by said optimal step which makes motion vector selection containing further the step to which said rate distortion criterion is fitted according to motion precision which is different in order [said] to determine both said optimal motion vectors and said optimal motion precision using a rate distortion criterion.

[Claim 18] Said step which searches 2nd at least one optimal motion vector in 2nd at least one motion precision is the search approach with an adaptable motion precision for presuming the motion vector according to claim 16 characterized by including further the step which is 2nd at least one motion precision finer than said 1st motion precision, and searches 2nd at least one optimal motion vector.

[Claim 19] It is the search approach with an adaptable motion precision for presuming the motion vector according to claim 16 characterized by said optimal step which makes motion vector selection containing further the step which uses the rate distortion criterion of a "distortion +Lx bit" mold in order [said] to choose said

optimal motion vector using a rate distortion criterion.

[Claim 20] By finding out the optimal motion vector to one macro block It is the search approach with an adaptable motion precision for presuming the motion vector in motion compensation animation coding (a). The step which searches one motion precision over the one optimal motion vector of said macro block, (b) The code from the variable-length sign (VLC) table interpreted by differing in the coding unit which changes with related motion vector precision is used. Step which encodes said motion precision (c) The search approach with an adaptable motion precision for presuming the motion vector characterized by changing including the step which encodes said optimal motion vector in each precision space.

[Claim 21] By finding out one optimal motion vector to one macro block, it is a system for presuming the motion vector in motion compensation animation coding (a). In order to find out the optimal motion vector V2 The 1st encoder for searching the set [1st] motion vector candidate of centering on V1 square within the limits defined beforehand on a partial pixel resolution grid (b) In order to find out the optimal motion vector V3 The 2nd encoder for searching the set [2nd] motion vector candidate of centering on V2 square within the limits defined beforehand on a partial pixel resolution grid, (c) In order to find out said optimal motion vector of said macro block The system for presuming the motion vector characterized by changing including the 3rd encoder for searching the set [3rd] motion vector candidate of centering on V3 square within the limits defined beforehand on a partial pixel resolution grid.

[Claim 22] The system for presuming the motion vector according to claim 21 characterized by said 1st encoder, the 2nd encoder, and the 3rd encoder being single encoders.

DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Field of the Invention] Especially this invention relates to the effective approach of presuming the motion vector in motion compensation animation coding, and encoding about bit compression or the coding approach of a digital animation.

[0002]

[Description of the Prior Art] In the conventional motion presumption approach, the present frame to encode is called "a macro block", for example, is divided into an image block with a same size of 16x16 pixels. An encoder searches the frame ("reference frame") inner block encoded before being most in agreement with the present macro block for every ** macro block. The coordinate movement magnitude during the macro block which is [in one present macro block and reference frame] most in agreement is expressed by the two-dimensional vector ("motion vector") of a macro block. Each component of a motion vector is measured per pixel.

[0003] For example, when the same location has the reference macro block which is most in agreement with the present macro block, as a quiescence background image is a typical example, the motion vectors of the present macro block are (0, 0). Motion vectors when a reference macro block most in agreement is discovered on the right from the coordinate of the present macro block in the location of 3 pixels at 2 pixels and a top are (2, 3). ** -- it is said that a motion vector [like] has the precision of an integer pixel (or a "integer pel" or a "perfect pel") since the horizontal component X and the vertical component Y have the integer pixel value. In drawing 1, vector V1= (1 1) expresses the motion vector of the perfect pel to the present macro block of arbitration.

[0004] The migration object in an animation scene does not move to a frame per integer pixel increment from a frame, carrying out a deer. A true motion takes the real number value which met in X and the direction of Y. Therefore, the reference macro block which is well in agreement with the present macro block has often discovered by searching the macro block which is [in the frame which interpolated the front frame by the factor (factor) of NxN, and then interpolated it] most in agreement. A motion vector can take the delta value of a 1-/N pixel along with X and Y, and if it has the

precision of a $1/N$ pixel (or $1/N$ pel), it will be expressed.

[0005] "The response to the proposal appeal to H.26L specification (Response to Call for Proposals for H.26L)" (Q. 15/SG16, document Q15-F-11, Seoul, November, 1998) of an ITU telecommunication standardization section and "strengthening (Enhancement of the Telenor Proposal for H.26L) of the proposal of Telenor to H.26L specification" (Q. -- 15/SG16, document Q15-G-25, and Monterey --) of an ITU telecommunication standardization section It will set in February, 1999 and is Gisle. Bjoitegaard proposed the motion vector of $1/3$ pel precision, and use of cube-like interpolation about animation coding specification H.26L ("Telenor encoder"). or [that a cube-like interpolation filter is used for a Telenor encoder, and it interpolates a reference frame 3×3 times in order to carry this out] -- or "a rise sampling" is carried out. This interpolation version needs 9 times as much memory as a reference frame. In one given macro block, a Telenor encoder presumes the optimal motion vector at two steps. That is, an encoder searches for the optimal integer pel vector first, and searches for vector $V_{1/3}$ of the optimal $1/3$ -pixel precision near V_1 next. In the example of drawing 1 , a total of 8 blocks of (16×16 pixels) of a 3×3 interpolation reference frame is investigated, and the block most in agreement that is a block relevant to motion vector $V_{1/3} = (VX, VY) = (3 \frac{1}{3}, 1 \frac{1}{3})$ like illustration is found out. This Telenor encoder has some problems. in order [first,] to calculate the motion vector of $1/3$ pel precision -- a part -- it is using the optimal fast search strategy and a complicated cube filter (setting on a whole page story). As a result, the calculated motion vector requires storage capacity and computational complexity that it is not the optimal and immense, and attaches them very at an expensive price. furthermore, this Telenor encoder chooses a better motion precision, using [therefore] the precision by the effective rate distortion criterion fixed to $1/3$ pixel -- as -- it cannot be adapted. Similarly, since the variable-length sign ("VLC") table of this Telenor encoder has the precision fixed to $1/3$ pixel, it cannot perform an interpretation which cannot be adapted to a different precision and is different.

[0006] Although a motion vector is presumed and it encodes with $1/2$ -pixel precision by the animation compression approach learned best, the reason is that according to old research it had suggested that additional compression gain was not acquired only by count becoming complicated in the motion precision which has adaptability more or it was more high. However, research old [these] did not presume a motion vector using the optimization rate distortion criterion, it did not use the convex property of criteria [like] in order to decrease complication of count, and it did not use the effective strategy which encodes the precision of a motion vector and a motion

vector.

[0007] ** -- as one of the researches old [like] -- Bernd Girod The paper (it is henceforth written as the paper of Girod) "motion compensation prediction (Motion-Compensating Prediction with Fractional-Pel Accuracy) by fraction pel precision" (the IEEE communication link report, volume [41st] No. 4, 604 – 612 pages, April, 1993) of Girod is mentioned. The paper of this Girod is the first fundamental analysis about the advantage which uses the motion precision of a partial pixel (subpixel) for animation coding. In order to search for the optimal motion vector in partial pixel space, the easy hierarchy strategy was used for Girod. in order that he may choose the optimal motion vector to a given precision again -- an arithmetic average -- absolute -- the criteria of difference ("MAD") were used. Since this optimal precision is based on the idealized assumption, it is chosen using an impractical formula, and it is very complicated and all motion vectors are restricted to a thing with the same precision in one frame. Finally, Girod did not mention the usage of the bit for encoding a motion vector only paying attention to prediction error energy.

[0008] As research old [other], it is Smita. Gupta and Allen The paper (it is henceforth written as "the paper of Gupta") "motion presumption (On Fractional Pixel Motion Estimation) of a fraction pixel" (a SPIE VCIP report, 2094 pages [408 – 419], Cambridge, November, 1993) of Gersho is mentioned. The paper of this Gupta has presented the approach of calculating and choosing a motion vector and encoding in partial pixel precision, for animation compression. the formula based on an average square error ("MSE") and congruence linear interpolation in the paper of Gupta -- indicating -- this formula -- using -- an ideal motion vector -- finding out -- ** -- the vector [like] was quantized for a desired motion precision. This optimal motion vector to a given precision was determined using the partial optimal MSE criterion, and this optimal precision was chosen using the approach of carrying out the maximum reduction of the energy difference per distortion bit. this is the criterion (a part -- the optimal) for which it craved. Coding of a given motion vector was performed by the approach of encoding in $1/2$ pel precision first, and then encoding to high degree of accuracy more in a circumstantiation bit. Coding of rough ** detailed ** is disagreeable ***** which needs a remarkable bit.

[0009] The optimal motion vector precision in the case of the motion compensation animation encoder based on a paper" block () [On the Optimal Motion Vector Accuracy for Block-Based Motion-Compensated] In Video Coders" (the compression report of an IST/SPIE digital animation: an algorithm, a technique, 302 – 314 pages, San Jose, February, 1996) (it is henceforth written as the paper of Ribas)

Jordi Ribas-Corbera and David L. Neuhoff modeled the effect of the bit rate on motion precision, and proposed some methods of presuming the optimal precision which makes a bit rate min. The paper of this Ribas described the full search approach for calculating the motion vector to arbitration precision, and took only congruence linear interpolation into consideration. The optimal motion vector was discovered by making MSE into min, and the optimal precision was chosen using some formulas drawn by optimization of rate distortion. To real-time equipment, mounting encoded a motion vector and precision using the difficult complicated frame adaptation entropy encoder.

[0010] a paper -- " -- the proposal () of the new core experiment about prediction strengthening with a high bit rate [Proposal for a new core experiment on Prediction enhancement at higher] bitrates" (coding ISO/IEC JTC1/SC29/WG11 animation and voice) The performance evaluation of the mounting equipment which mitigated the complexity for MPEG 97/1827, SEBIRIA, February, 1997, and "1 / 4 pel motion compensation () [Performance Evaluation of a Reduced Complexity] In Implementation for Quarter Pel Motion Compensation" (coding of ISO/IEC JTC1/SC29/WG11 animation and voice, MPEG 97/3146, San Jose, January, 1998) Ulrich Benzler Use of the motion vector of 1 / 4 pel precision and use of the interpolation filter with which MPEG4 animation coding criteria progressed further were proposed for the animation sequence. However, Benzler used the fast search method of Girod for discovery of the motion vector of 1/4 pel. Although Benzler did not take a different interpolation filter into consideration, it proposed using a easier filter in the 2nd step in the 1st step using a composite filter, and interpolated one macro block at once. Although a lot of [this approach] cache memory is not needed, it is complicated, and computational complexity is great, in order to calculate all motion vectors in all possible mode (for example, 16x16, 8x8, 4x4) per 1 / 4 pel precision within one macro block and to determine the optimal mode. Benzler used the MAD criterion and discovered the optimal motion vector fixed to 1 / 4 pel precision to all sequences. Therefore, the approach of choosing the optimal motion precision was not shown. Finally, Benzler encoded the motion vector using the usable variable-length sign ("VLC") table, in order to encode the vector of 1/2 and 1/4-pixel precision.

[0011]

[Problem(s) to be Solved by the Invention] the rate distortion criteria which optimized above-mentioned bibliography -- using -- a motion vector -- not presuming -- ** -- the complexity of count is not mitigated using the convex property of criteria [like]. Furthermore, the effective strategy which encodes a motion vector and precision is

not used for such bibliographies.

[0012]

[Means for Solving the Problem] One operation gestalt of this invention solves the problem of the conventional technique by calculating the motion vector of high pixel precision (called a "fraction" or "partial pixel" precision) by the increment in slight computational complexity.

[0013] If the strategy of this invention is used, it is clear by experiment that an animation encoder can attain remarkable compression gain (for example, reduction of the bit rates which reach to 30% as compared with classic selection of motion precision) on equivalent count level. Since it is adapted for motion precision and is calculated and chosen as it, this invention can be described as an adaptation motion precision ("AMA") method.

[0014] One of the desirable operation gestalten of this invention searches the optimal motion vector smartly using the fast search strategy in partial pixel (subpixel) space. This technique presumes the motion vector at the time of motion compensation animation coding by discovering the optimal motion vector to 1 macro block. Within the grid of the partial pixel resolution of the square range which has a core in V1 and which was appointed beforehand, the 1st step searches a set [1st] motion vector candidate, and finds out the optimal motion vector V2. Next, within a grid with the partial pixel resolution of the square range which has a core in V2 and which was appointed beforehand, it looks for a set [2nd] motion vector candidate, and the optimal motion vector V3 is found out. Then, within a grid with the partial pixel resolution of the square range which has a core in V3 and which was appointed beforehand, it looks for a set [3rd] motion vector candidate, and the optimal motion vector of a macro block is found out.

[0015] In another desirable operation gestalt of this invention, a highly precise motion vector presumption technique can reduce the complexity of count using a different interpolation filter in a different phase.

[0016] Another desirable operation gestalt of this invention chooses the optimal vector and precision about rate distortion (RD). This operation gestalt determines both the optimal motion vector and the optimal motion precision using the rate distortion criterion which corresponds according to a different motion precision.

[0017] variable length coding (VLC) with still more nearly another, effective desirable operation gestalt of this invention — a motion vector and precision are encoded by law. This technique uses the VLC table according to a related motion vector precision in which an interpretation which is different in a different coding unit is possible.

[0018] **** and other purposes, the description, and advantage of this invention will be easily understood, if the following detailed explanation of this invention is read with reference to an accompanying drawing.

[0019]

[Embodiment of the Invention] Although it moves in each image block, and precision is changed and being explained, many approaches of this invention can be applied also when changing precision for every immobilization or frame to all sequences. This invention is described again as what uses the animation encoder (and specially encoder of Telenor) of Telenor, as the background of invention was described. Although explained using the vocabulary of the animation encoder of Telenor, the technique described here is applicable to other motion compensation animation encoders of arbitration.

[0020] Many of animation encoders use the motion vector and congruence linear interpolation of half-pixel (or "1/2 pel") precision. 1 / 2 pel motion vector, and congruence linear interpolation are used for the 1st version of the encoder of Telenor. However, the latest version of the encoder of Telenor builds in 1 / 3 pel vector, and the cube form interpolation function, in order to acquire the further compression gain. Especially, in one given macro block, the encoder of Telenor presumes the optimal motion vector at two steps shown in drawing 2 . First, this Telenor encoder searches for the optimal integer pel vector V1 (drawing 1) (step 100). Next, this Telenor encoder searches 1/3 pel precision vector V1/3 with the V1 optimal neighborhood (drawing 1) (step 102). this 2nd step finds out the block which it all (it has the pixel train of each 16x16) comes out in a 3x3 interpolation (interpolation) reference frame, investigates eight blocks, and is most in agreement, as shown in the graph of drawing 1 . The motion vector of eight blocks is expressed as eight real points into the grid which has a core in V1. In drawing 1 , the block relevant to motion vector V1 / 3=(VX, VY) = (3 1+1/1) is most in agreement.

[0021] According to the technique of this invention, an encoder can choose precision using either a full search strategy or a fast search strategy between the groups (for example, 1/2, 1/3, and 1 / 6 pel precision motion vector) of the motion precision of arbitration.

[0022] (Search strategy of a full search AMA method) As shown in drawing 3 and drawing 4 , in the case of this full search adaptation motion precision (AMA) method search strategy, a Telenor encoder searches all the motion vector candidates on five the "(it defines as a square block specified with the number of upper part pixels, the number of lower part pixels, and the number of pixels of both sides) square range" of a

pixel and the grids of 1/6-pixel resolution which are shown in drawing 3 . As shown in drawing 4 , at the 1st step (104) of the full search AMA, the optimal integer pel vector V1 (drawing 1) is searched. In the 2nd step (106) of the full search AMA, an encoder searches 1/6 pixel precision vector V1/6 with the V1 optimal neighborhood (drawing 3). If it puts in another way, this full search AMA will change the 2nd step of a Telenor process, and the motion vector candidate in the partial pixel location of the others [encoder] in velocity space will also enable it to search it. This purpose is discovering the optimal motion vector in a grid, i.e., the vector which directs the block (inside of a interpolation reference frame) which is most in agreement with the present macro block. Although count is complicated since this full search strategy searches 120 partial pixel candidates, the total potential of this operation gestalt of this invention is shown.

[0023] The important technical problem in a motion vector search is selection of the judgment measure or criteria of deciding the block which coincides with a given macro block most. actual -- almost all approaches -- an average square error (MSE) or an average -- absolute -- which criterion of difference (MAD) is used. MSE during two blocks subtracts the pixel value of two blocks, squares a pixel value difference, and takes the average. MAD during two blocks -- difference -- square -- except for calculating the absolute value of a pixel value difference instead of count, it is the same distortion measure. If two image blocks are mutually similar, the value of MSE and MAD is small. However, these values are large if an image block is not similar. Therefore, a typical animation encoder finds out the macro block which coincides with a macro block most by choosing the motion vector which brings about any of the minimum MSE or the minimum MAD they are. In other words, the block relevant to the optimal motion vector is a block of most approximation in a given macro block in MSE or MAD.

[0024] Though regrettable, the distortion measure of MSE and MAD is not taking into consideration the cost of the bit which actually encodes a vector. For example, although MSE is made as for one arbitration motion vector to min, the cost encoded in a bit may be very high, and may not be the optimal selection from a viewpoint of coding.

[0025] In order to deal with this problem, the newest encoder which Telenor has described chooses the optimal motion vector using the rate distortion (RD) criterion of a "distortion +Lx bit" form. A "distortion" value is MSE or MAD typically, "L" is a constant depending on compression level (namely, quantization step size), and a "bit" is the number of bits which coding of a motion vector takes. Generally, this type of

every RD criterion can be used for this invention. However, in the case of this invention, the "bit" contains the bit which coding of a vector takes, and the bit which coding of the vector precision takes. In fact, since some candidates have some precision modes, it can have the "bit" value of the number of some. For example, the candidate in a location $(1/2, -1/2)$ can also consider suddenly $1/2$ or $1/6$ -pixel precision.

[0026] (Fast search AMA method search strategy) As shown in drawing 5 and drawing 6, in the case of a fast search adaptation motion precision (AMA) method search strategy, an encoder investigates only a motion vector candidate's small set. At the 1st step (108) of the fast search AMA, as for an encoder, one side checks eight motion vector candidates of the square (inside of the square range 1) of 1 with a core in the grid of $1/2$ -pixel resolution to V1. V2 is set up in order to express the candidate (namely, eight last vectors and what is the optimal in V1) who has the minimum RD cost (110). Next, an encoder has a core in V2 on the grid of $1/6$ -pixel resolution, and one side checks the motion vector location of eight pieces in the square of 1 (112). When V2 has minimum RD cost (114), an encoder stops retrieval and chooses it as a motion vector of a block of V2. Otherwise, V3 is set up in order to express the optimal thing in eight last vectors (116). An encoder searches the new motion vector candidate in the square range 1 which has a core in V3 in the grid of $1/6$ -pixel resolution next (118). Some candidates in this grid should be cautious of it being already check ending and being able to fly. At this last step, it chooses as a motion vector of a block of a candidate with the minimum RD cost (120).

[0027] According to experimental data, since this easy fast search strategy checks RD cost of about 18 typical location in partial (there are more ten pieces than Telenor retrieval strategy) pixel space on an average therefore, the complexity of count as the whole stops at a moderate increment.

[0028] It is shown that the experimental result explained below in relation to drawing 8 thru/or drawing 18 actually has no loss of the compressive ability by using the fast search version of this AMA method. That reason is that this fast search AMA retrieval strategy is utilizing the degree of convex of a "distortion +Lx bit" curve (it is known that "distortion" is convexity) by founding the pass with which RD cost shifts to a low smartly from a high level.

[0029] Another embodiment of this invention changes more than one or it of the step 108-120. These operation gestalten are also efficient and the number of motion vector candidates checked in partial pixel velocity space is reduced further.

[0030] In the example of drawing 7, the candidate of $1/3$ pel precision is checked. In

this example, step 112 is replaced by one of the three possible scenarios. First, if there is optimal motion vector candidate from step 110 at the core of V1 ("integer pel vector") (130), an encoder will check three candidates of 1 / 3 pel precision between a main vector, and 1 / 2 pel location which has the minimum RD cost next (132). next -- if the optimal motion vector candidate from step 110 is the vector of a corner (134) -- an encoder -- ** -- 4 vector candidates of 1 / 3 pel precision nearest to a corner vector [like] are checked (136). If the optimal motion vector candidate from step 110 is [3rd] between two corner vectors (138), an encoder will determine the one where RD cost is lower in two corner vectors, and will check the optimal motion vector candidate from step 110, and 4 vector candidates of 1 / 3 pel precision nearest to the straight line between corners [like] (140). In case there is no V2 in a core, it must be between two corners again when there is nothing also by the corner vector, and this process is performed, it should be cautious of step 138 becoming unnecessary. When setting an encoder as retrieval of the motion vector of 1/3-pixel precision, drawing 7 can be changed so that it may become the termination instead of continuation to step 114.

[0031] (Reduction of computational complexity and memory) At step 108, in order to check only the motion vector candidate of 1/2-pixel precision, the computational complexity and memory which mounting of hardware and software takes are reduced sharply. Especially, in smart mounting of this fast search, a reference frame interpolates only 2x2 and obtains RD cost to 1 / 2 pel vector candidate. the fast (or cache) memory for hardware or software encoders is remarkable as compared with the approach of Telenor required in order that only 3x3 may interpolate a reference frame -- amount reduction is carried out. As compared with the encoder of Telenor, cache memory becomes 9/4 of reduction, or 2.25 times as many reduction as this. Some additional interpolation can be performed per block later.

[0032] Furthermore, since the interpolation in step 108 is used so that a search may be oriented in the direction which lowers RD cost function value, a composite filter is not needed for these interpolation. Therefore, computational complexity is reducible by using the easy congruence linearity filter for steps 108.

[0033] Moreover, since such decision does not have the significant profits by using high degree of accuracy, a decision about other main coding like selection of a macro block mode (for example, 16x16, four 8x8 grades) can be made using 1 / 2 pel vector. Next, since an encoder interpolates a required partial pixel value to some additional vector candidate who checks in the remaining step, it can use a complicated cube (3rd order) filter. Since a macro block mode is already selection ending, it is necessary to

carry out interpolation of these last to selection mode.

[0034] By using two or more filters, it always compares with the approach of Telenor using cube interpolation, and is Sparc. Ultra Reduction of the computational complexity which exceeds 20% by the operation time in 10 mold workstation was obtained. Furthermore, the need for fast memory decreased in abbreviation one half. Moreover, about compressive ability, **** was almost without a loss. In a comparison with 1 operation gestalt of this fast search, it is only that this invention requires about seven interpolation per pixel to Benzler technique needing interpolation of about 70 per pixel in a Telenor encoder.

[0035] (Bit coding of a motion vector and precision) If the optimal motion vector and precision are determined, an encoder will encode both a motion vector and a precision value in a bit. One approach adds some extra bits, in order to encode a motion vector in a given precision (for example, half-pixel precision), next to detail the vector for a higher motion precision. Although this is the strategy which B.Girod proposed, it is suboptimization in respect of rate distortion.

[0036] With one desirable operation gestalt of this invention, it encodes first using an easy sign as showed the precision of the motion vector to one macro block in Table 1. It is also possible to use other tables of code length's {1, 2, 2}'s arbitration. A bit rate can be further decreased using the typical DPCM method.

[0037]

[Table 1]

[0038] Next, the vector value in each precision space is encoded. These bits can be obtained from the item of a single VLC table which is used in an H26L codec. An important idea is these bits' changing with motion precision of a macro block, and interpreted. For example, when motion precision is 1/3 and the sign bit to X component of a different motion vector is 000011, X components of a vector are $V_x=2/3$. If precision is 1/2, X component of a vector is equivalent to $V_x=1$.

[0039] The approach of this invention is used for encoding the vector of the motion precision of arbitration as compared with the approach of Benzler which encodes a motion vector on the variable-length sign (VLC) table which can be used for coding of

1/2 and a 1/4-pixel precision vector, and in each frame and a macro block, tables differ and can be interpreted. Furthermore, it is not necessary to be a multiple mutually or, and the overall approach of this invention can be applied to the motion precision of arbitration, and does not need to be a 1/n (n is integer) mold. Counting of the number of increments in given partial pixel space is carried out simply, and it uses the bit in the related item of a table as a sign. From a viewpoint of a decoder, if motion precision is decoded, a motion vector can also be decoded easily. Then, the related block in a front frame is reconstructed using the cube interpolator of four typical taps. A different 4 tap filter for every motion precision exists. Since the number of actuation which reconstruction of a prediction block takes an AMA method is the same and it is unrelated to motion precision, complexity of decode is not increased.

[0040] (Experimental result) Drawing 8 thru/or drawing 18 show the result of having examined the coding codec of Telenor, without not using AMA or using it by various animation sequences, resolution, and frame rates of a publication in Table 2. These drawings plot rate distortion ("RD") for every case. The "Anchor" curve shows RD point from optimization H.263+ (only drawing 8 and drawing 9). Telenor 1/"2+b" curve shows Telenor (classic example) by 1 / 2 pel vector, and congruence linear interpolation. The "Telenor 1/3" curve shows the proposal ("Telenor encoder") of the present Telenor. The "Telenor+AMA+c" curve shows the Telenor encoder by the full search strategy of this invention. The "Telenor+FSAMA+c" curve shown in drawing 15 thru/or drawing 17 shows the Telenor encoder by the fast search strategy of this invention. (As long as there was no other convention, the full search version of AMA was the strategy of the encoder used for the experiment.) All the test results performed the crosscheck in the encoder and the decoder. When these results carry out AMA, the gain in the peak ("PSNR") of a signal-to-noise (noise) ratio exceeds H26L, is 1dB in height, and is still higher than a classic example.

[0041]

[Table 2]

[0042] The animation sequence is used in common by the animation coding community except for "shaking Paris." The latter is the synthetic animation obtained when only the motion vector to which X and Y component take any value in the range of $[-1 \text{ and } 1]$ moved the sequence "Paris" known well. This synthetic animation simulates the small motion produced with the stock camera in the typical animation telephone scene.

[0043] (Comparison of the full search of a motion precision adaptation (AMA) method, and a fast search) the experimental result shown in drawing 16 and 17 shows that the usability ability of the encoder of a fast search strategy ("Telenor FSAMA+c") and a full search strategy (Telenor AMA+c -- ") method about AMA is the same in fact. Since a fast search strategy uses the convexity of RD cost curve in partial pixel velocity space, this is infallible. Since in other words the configuration of RD cost curve follows a gently-sloping convex curve, the minimum value can be easily discovered using some smart fast search schemes which drop a curve.

[0044] (Association of AMA and a plurality reference frame) In the graph shown in drawing 18, the curve with the indicator of "1r" used only one reference frame for the motion compensation. Therefore, these curves are the same as the curve shown in drawing 10. The curve with the indicator of "5r" used five reference frames. The experiment shows that the gain by AMA is added to the curve obtained using two or more reference frames. The gain by AMA in the case of one reference frame can be measured by comparing the curve (notes: introductory notes x and **) of green and pink, and the gain in the case of five reference frames can be measured between the curves (notes: introductory notes O and -) of blue and red.

[0045] Although a frame which especially the thing which should be careful of can carry out this invention with a frame level, and is different can use a different motion precision, it is using the same precision for all the motion vectors in one frame. As for motion vector precision, in this operation gestalt, being only once signal-ized in a frame layer is desirable. It is shown that compression gain which was shown per case of macro block adaptation also by using the optimal fixed motion precision to all frames produces an experiment.

[0046] In the operation gestalt of other frame bases, an encoder can perform a motion compensation on the whole frame in a different vector precision, and can choose the optimal precision in accordance with RD criterion after that. Although this approach is not suitable for the one pass encoder of a pipelined architecture, it is applicable to the encoder of the software base, or more complicated coding. In the operation gestalt of

other frame bases, in order that an encoder may predict the optimal precision over a given frame, a former statistic and/or a former formula can be used (for example, the formula described by the paper of Ribas or its version can be used). Although this approach depends for engine-performance gain on the precision of the formula used for prediction, it is suitable for the one pass encoder.

[0047] what the vocabulary and expression which were used for the above-mentioned specification are a thing for explanation, and is restricted -- it is not -- ** -- in using the vocabulary and an expression, there is no intention which eliminates the vocabulary and an expression with equivalent description of a display and description or its part, and it checks that the range of this invention is specified and limited by only the claim of a claim. [like]

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]

[Drawing 1] It is drawing showing the example of the location of the perfect pel in velocity space, and $1/3$ pel.

[Drawing 2] It is a flow chart Fig. for explaining the approach by the conventional technique of presuming the optimal motion vector.

[Drawing 3] It is drawing showing the example of the motion vector candidate location at the time of the full search in partial pixel velocity space.

[Drawing 4] It is a flow chart Fig. for explaining the desirable embodiment of the optimal motion vector presumption approach of the full search method by this

invention.

[Drawing 5] It is drawing showing the example of the motion vector candidate location at the time of the fast search in partial pixel velocity space.

[Drawing 6] It is a flow chart Fig. for explaining the desirable operation gestalt of the optimal motion vector presumption approach of the fast search method by this invention.

[Drawing 7] It is a flow chart Fig. for explaining another desirable operation gestalt of step 114 of drawing 6 .

[Drawing 8] It is the graphical representation showing the result of having run the performance test of a Telenor encoder without having set to the animation sequence "a container" and using or using adaptation motion precision (AMA) in the frame rate of per second ten frames, and resolution QCIF.

[Drawing 9] It is the graphical representation showing the result of having run the performance test of a Telenor encoder without having set to the animation sequence "news" and using or using adaptation motion precision (AMA) in the frame rate of per second ten frames, and resolution QCIF.

[Drawing 10] It is the graphical representation showing the result of having run the performance test of a Telenor encoder without having set to the animation sequence "an automobile" and using or using adaptation motion precision (AMA) in the frame rate of per second ten frames, and resolution QCIF.

[Drawing 11] It is the graphical representation showing the result of having run the performance test of a Telenor encoder without having set to the animation "a garden" and using or using adaptation motion precision (AMA) in the frame rate of per second 15 frames, and resolution SIF.

[Drawing 12] It is the graphical representation showing the result of having run the performance test of a Telenor encoder without having set to the animation sequence "a garden" and using or using adaptation motion precision (AMA) in the frame rate of per second 15 frames, and resolution QCIF.

[Drawing 13] It is the graphical representation showing the result of having run the performance test of a Telenor encoder without having set to the animation sequence "Tempete" and using or using adaptation motion precision (AMA) in the frame rate of per second 15 frames, and resolution SIF.

[Drawing 14] It is the graphical representation showing the result of having run the performance test of a Telenor encoder without having set to the animation sequence "Tempete" and using or using adaptation motion precision (AMA) in the frame rate of per second 15 frames, and resolution QCIF.

[Drawing 15] It is the graphical representation showing the result of having run the performance test of a Telenor encoder without having set to the animation sequence "shaking Paris" and using or using adaptation motion precision (AMA) in the frame rate of per second 15 frames, and resolution QCIF.

[Drawing 16] In an animation sequence "an automobile", it is the graphical representation showing the result of the performance test of a fast search strategy ("Telenor FSAMA+c") and a full search strategy ("Telenor AMA+c") in the frame rate of per second ten frames, and resolution QCIF.

[Drawing 17] It is the graphical representation showing the result of the performance test of a fast search strategy ("Telenor FSAMA+c") and a full search strategy ("Telenor AMA+c") in the frame rate of per second ten frames, and resolution QCIF in an animation sequence "a container."

[Drawing 18] It is the graphical representation showing the performance test result which compares the case where it examines using two or more frames the case where it examines by resolution QCIF and the frame rate of per second ten frames in an animation sequence "an automobile" only using one reference frame for a motion compensation, and for a motion compensation.

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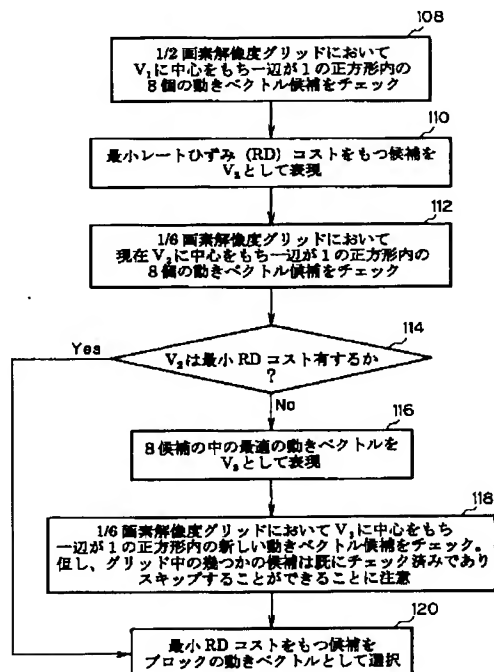
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(54) 【発明の名称】 適応性のある動き精度をもった動き推定方法

(57) 【要約】

【課題】 計算量の増加が少ない高画素精度の動きベクトルの計算技法を含む適応性のある動き精度をもった動き推定方法を提供する。

【解決手段】 1つの技法は、最適動きベクトルをスマートに探索する部分画素空間におけるファストサーチ戦略を用いる。別の技法は、異なる段階で異なる補間フィルタを用い高精度動きベクトルを推定して、計算の複雑さを軽減する。他の技法は、異なる動き精度に従って適応するレートひずみ判定基準を用いて最適の動きベクトルと最適の動き精度の両方を決定する。さらに他の技法は、関連動きベクトル精度に従い異なる符号化単位において異なって解釈されるVLCテーブルを使用する。



【特許請求の範囲】

【請求項1】 1つのマクロブロックに対する最適な動きベクトルを見つけ出すことにより、動き補償動画符号化における動きベクトルを推定するための、ファストサーチ適応性のある動き精度をもったサーチ方法であって、

(a) 最適動きベクトル V_1 を見つけ出すために、部分画素解像度グリッド上で V_1 を中心とする予め定められた正方形範囲内の動きベクトル候補の第1セットをサーチするステップと、(b) 最適動きベクトル V_3 を見つけ出すために、部分画素解像度グリッド上で V_2 を中心とする予め定められた正方形範囲内の動きベクトル候補の第2セットをサーチするステップと、

(c) 前記マクロブロックの前記最適な動きベクトルを見つけ出すために、部分画素解像度グリッド上で V_3 を中心とする予め定められた正方形範囲内の動きベクトル候補の第3セットをサーチするステップとを含んで成ることを特徴とする動きベクトルを推定するためのファストサーチ適応性のある動き精度をもったサーチ方法。

【請求項2】 最適動きベクトル V_2 を見つけ出すために、部分画素解像度グリッド上で V_1 を中心とする予め定められた正方形範囲内の第1セットの動きベクトル候補をサーチする前記ステップは、最適動きベクトル V_2 を見つけ出すために、 $1/2$ 画素解像度グリッド上で V_1 を中心とする正方形範囲1内の8個の動きベクトル候補の第1セットをサーチするステップをさらに含むことを特徴とする請求項1に記載の動きベクトルを推定するためのファストサーチ適応性のある動き精度をもったサーチ方法。

【請求項3】 最適動きベクトル V_3 を見つけ出すために、部分画素解像度グリッド上で V_2 を中心とする予め定められた正方形範囲内の第2セットの動きベクトル候補をサーチする前記ステップは、最適動きベクトル V_3 を見つけ出すために、 $1/6$ 画素解像度グリッド上で V_2 を中心とする正方形範囲1内の8個の動きベクトル候補の第2セットをサーチするステップをさらに含むことを特徴とする請求項1に記載の動きベクトルを推定するためのファストサーチ適応性のある動き精度をもったサーチ方法。

【請求項4】 V_2 が最小レート歪みコストを有する場合に前記ブロックに対する動きベクトルとして V_2 を使用するステップと、請求項1のステップ(c)をスキップするステップとをさらに含むことを特徴とする請求項1に記載の動きベクトルを推定するためのファストサーチ適応性のある動き精度をもったサーチ方法。

【請求項5】 前記マクロブロックの前記最適な動きベクトルを見つけ出すために、部分画素解像度グリッド上で V_3 を中心とする予め定められた正方形範囲内の第3セットの動きベクトル候補をサーチする前記ステップは、前記マクロブロックの前記最適な動きベクトルを見つけ出すために、 $1/6$ 画素解像度グリッド上で V_3 を

中心とする正方形範囲1内の8個の動きベクトル候補の第3セットをサーチするステップをさらに含むことを特徴とする請求項1に記載の動きベクトルを推定するためのファストサーチ適応性のある動き精度をもったサーチ方法。

【請求項6】 前記マクロブロックの前記最適な動きベクトルを見つけ出すために、部分画素解像度グリッド上で V_3 を中心とする予め定められた正方形範囲内の第3セットの動きベクトル候補をサーチする前記ステップは、前記第3セットの動きベクトル候補中の既にテスト済みの候補をスキップするステップをさらに含むことを特徴とする請求項1に記載の動きベクトルを推定するためのファストサーチ適応性のある動き精度をもったサーチ方法。

【請求項7】 前記第1セットの動きベクトル候補をサーチする前記ステップは、第1の補間を行うために第1のフィルタを使用して前記第1セットの動きベクトル候補をサーチするステップをさらに含み、前記第2セットの動きベクトル候補をサーチする前記ステップは、第2の補間を行うために第2のフィルタを使用して前記第2セットの動きベクトル候補をサーチするステップをさらに含み、前記第3セットの動きベクトル候補をサーチする前記ステップは、第3の補間を行うために第3のフィルタを使用して前記第3セットの動きベクトル候補をサーチするステップをさらに含むことを特徴とする請求項1に記載の動きベクトルを推定するためのファストサーチ適応性のある動き精度をもったサーチ方法。

【請求項8】 最適動きベクトル V_3 を見つけ出すために、部分画素解像度グリッド上で V_2 を中心とする予め定められた正方形範囲内の第2セットの動きベクトル候補をサーチする前記ステップは、(a) V_2 が中心にある場合、 $1/3$ ピクセル精度の3候補 V_2 と次に最低のRDコストをもつ $1/2$ ピクセル位置をサーチするステップと、(b) V_2 がコーナーのベクトルである場合は、 V_2 に最も近い $1/3$ ピクセル精度の4ベクトル候補をサーチするステップと、(c) V_2 が2つのコーナーベクトル間にある場合は、2つのコーナーの中のより低いRDコストをもつコーナーを決定し、より低いRDコストを持つ前記コーナーとの間のラインに最も近い $1/3$ ピクセル精度の4ベクトル候補をサーチするステップとをさらに含むことを特徴とする請求項1に記載の動きベクトルを推定するためのファストサーチ適応性のある動き精度をもったサーチ方法。

【請求項9】 1つのマクロブロックに対する最適な動きベクトルを見つけ出すことにより、動き補償動画符号化における動きベクトルを推定するための、適応性のある動き精度をもったサーチ方法であって、(a) 第1補間を行うための第1フィルタを用いて、最適動きベクトル V_2 を見つけ出すために、 V_1 を中心とするグリッド内の第1セットの動きベクトル候補をサーチするステッ

ブと、(b) 第2補間を行うための第2フィルタを用いて、最適動きベクトル V_3 を見つけ出すために、 V_2 を中心とするグリッド内の第2セットの動きベクトル候補をサーチするステップと、(c) 第3補間を行うための第3フィルタを用いて、前記マクロブロックの前記最適な動きベクトルを見つけ出すために、 V_3 を中心とするグリッド内の第3セットの動きベクトル候補をサーチするステップとを含んで成ることを特徴とする動きベクトルを推定するための適応性のある動き精度をもったサーチ方法。

【請求項10】 第1補間を行うための第1フィルタを用いてサーチする前記ステップは、粗い補間を行うための簡単なフィルタの使用をさらに含むことを特徴とする請求項9に記載の動きベクトルを推定するための適応性のある動き精度をもったサーチ方法。

【請求項11】 第1補間を行うための第1フィルタを用いてサーチする前記ステップは、粗い補間を行うための簡単なフィルタの使用をさらに含み、第2補間を行うための第2フィルタを用いてサーチする前記ステップは、細かい補間を行うための複合フィルタの使用をさらに含むことを特徴とする請求項9に記載の動きベクトルを推定するための適応性のある動き精度をもったサーチ方法。

【請求項12】 第3補間を行うための第3フィルタを用いてサーチする前記ステップは、細かい補間を行うための複合フィルタの使用をさらに含むことを特徴とする請求項11に記載の動きベクトルを推定するための適応性のある動き精度をもったサーチ方法。

【請求項13】 第1補間を行うための第1フィルタを用いてサーチする前記ステップは、 2×2 の参照フレームを補間するための双線形フィルタの使用をさらに含むことを特徴とする請求項9に記載の動きベクトルを推定するための適応性のある動き精度をもったサーチ方法。

【請求項14】 第1補間を行うための第1フィルタを用いてサーチする前記ステップは、 2×2 の参照フレームを補間するために双線形フィルタの使用をさらに含み、第2補間を行うための第2フィルタを用いてサーチする前記ステップは、細かい補間を行うための立方体フィルタの使用をさらに含むことを特徴とする請求項9に記載の動きベクトルを推定するための適応性のある動き精度をもったサーチ方法。

【請求項15】 第3補間を行うための第3フィルタを用いてサーチする前記ステップは、細かい補間を行うための立方体フィルタの使用をさらに含むことを特徴とする請求項14に記載の動きベクトルを推定するための適応性のある動き精度をもったサーチ方法。

【請求項16】 1つのマクロブロックに対する最適な動きベクトルを見つけ出すことにより、動き補償動画符号化における動きベクトルを推定するための、適応性のある動き精度をもったサーチ方法において、(a) 前

記マクロブロックの第1の最適動きベクトルに対する第1の動き精度をサーチするステップと、(b) 前記第1の最適動きベクトルと前記第1の動き精度を符号化するステップと(c) 少なくとも1つの第2の動き精度で前記マクロブロックの少なくとも1つの第2の最適動きベクトルをサーチするステップと、(d) 前記少なくとも1つの第2の最適動きベクトルと、前記少なくとも1つの第2の動き精度とを符号化するステップと、

(e) 前記第1と少なくとも1つの最適動きベクトルの中から前記最適な動きベクトルをレート歪み判定基準を用いて選択するステップとを含んで成ることを特徴とする動きベクトルを推定するための適応性のある動き精度をもったサーチ方法。

【請求項17】 レート歪み判定基準を用いて前記最適な動きベクトルを選択する前記ステップは、前記最適な動きベクトルと前記最適動き精度の両方を決定するために異なる動き精度に従って前記レート歪み判定基準を適応させるステップをさらに含むことを特徴とする請求項16に記載の動きベクトルを推定するための適応性のある動き精度をもったサーチ方法。

【請求項18】 少なくとも1つの第2の動き精度で少なくとも1つの第2の最適動きベクトルをサーチする前記ステップは、前記第1の動き精度より細かい少なくとも1つの第2の動き精度で、少なくとも1つの第2の最適動きベクトルをサーチするステップをさらに含むことを特徴とする請求項16に記載の動きベクトルを推定するための適応性のある動き精度をもったサーチ方法。

【請求項19】 レート歪み判定基準を用いて前記最適な動きベクトルを選択する前記ステップは、前記最適な動きベクトルを選択するために“歪み+L×ビット”型のレート歪み判定基準を使用するステップをさらに含むことを特徴とする請求項16に記載の動きベクトルを推定するための適応性のある動き精度をもったサーチ方法。

【請求項20】 1つのマクロブロックに対する最適な動きベクトルを見つけ出すことにより、動き補償動画符号化における動きベクトルを推定するための適応性のある動き精度をもったサーチ方法であって、(a) 前記マクロブロックの1つの最適動きベクトルに対する1つの動き精度をサーチするステップと、(b) 関連する動きベクトル精度により異なる符号化単位において異なって解釈された可変長符号(VLC)テーブルからのコードを用いて、前記動き精度を符号化するステップと

(c) 個々の精度空間において前記最適な動きベクトルを符号化するステップとを含んで成ることを特徴とする動きベクトルを推定するための適応性のある動き精度をもったサーチ方法。

【請求項21】 1つのマクロブロックに対する1つの最適な動きベクトルを見つけ出すことにより、動き補償動画符号化における動きベクトルを推定するためのシステムであって、(a) 最適動きベクトル V_2 を見つけ

出すために、部分画素解像度グリッド上で V_1 を中心とする予め定められた正方形範囲内の第1セットの動きベクトル候補をサーチするための第1符号化器と、(b)

最適動きベクトル V_3 を見つけ出すために、部分画素解像度グリッド上で V_2 を中心とする予め定められた正方形範囲内の第2セットの動きベクトル候補をサーチするための第2符号化器と、(c) 前記マクロブロックの前記最適な動きベクトルを見つけ出すために、部分画素解像度グリッド上で V_3 を中心とする予め定められた正方形範囲内の第3セットの動きベクトル候補をサーチするための第3符号化器とを含んで成ることを特徴とする動きベクトルを推定するためのシステム。

【請求項22】 前記第1符号化器、第2符号化器および第3符号化器が単一の符号化器であることを特徴とする請求項21に記載の動きベクトルを推定するためのシステム。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、デジタル動画のビット圧縮又は符号化方法に関し、特に、動き補償動画面符号化における動きベクトルを推定して符号化する効果的な方法に関する。

【0002】

【従来の技術】従来の動き推定方法において、符号化する現フレームを、“マクロブロック”と称する、例えば 16×16 ピクセルの同一サイズの画像ブロックに分割する。各現マクロブロック毎に、符号化器は、現マクロブロックに最も一致する、前に符号化されたフレーム（“参照フレーム”）内ブロックをサーチする。1個の現マクロブロックと参照フレーム内の最も一致するマクロブロック間の座標移動量は、マクロブロックの2次元ベクトル（“動きベクトル”）によって表現される。動きベクトルの各成分は画素単位で測定される。

【0003】例えば、現マクロブロックに最も一致する参照マクロブロックが同一位置にある場合、静止背景画像が代表的な例であるように、現マクロブロックの動きベクトルは(0, 0)である。最も一致する参照マクロブロックが、現マクロブロックの座標から右に2画素及び上に3画素の位置で発見された場合の動きベクトルは(2, 3)である。かような動きベクトルは、水平成分X及び垂直成分Yが整数画素値を有しているので、整数画素（又は“整数ペル”又は“完全ペル”）の精度を有すると云う。図1において、ベクトル $V_1 = (1, 1)$ は、任意の現マクロブロックに対する完全ペルの動きベクトルを表わしている。

【0004】動画シーン中の移動オブジェクトは、しかしながら、フレームからフレームへ整数画素増分単位では移動しない。真の動きは、X及びY方向に沿った実数値を取る。従って、現マクロブロックにより良く一致する参照マクロブロックは、前フレームを $N \times N$ の因子

（ファクタ）で補間し、次に補間したフレーム内の最も一致するマクロブロックをサーチすることにより発見できることがよくある。動きベクトルはXとYに沿って $1/N$ 画素の増分値を取ることができ、 $1/N$ 画素（又は $1/N$ ペル）の精度を有すると表現される。

【0005】ITU電気通信標準化部門の“H. 26 L規格に対する提案呼びかけへの応答（Response to Call for Proposals for H.26L）”（Q. 15/SG16, 文書Q15-F-11, ソウル, 1998年11月）及びITU電気通信標準化部門の“H. 26 L規格に対するTelenorの提案の強化（Enhancement of the Telenor Proposal for H.26L）”（Q. 15/SG16, 文書Q15-G-25, モントレー, 1999年2月）において、Gisle Bjoitegaardは、動画符号化規格H. 26 L（“Telenor符号化器”）に関し $1/3$ ペル精度の動きベクトルと立方体状補間法の使用を提案した。これを実施するために、Telenor符号化器は、立方体状補間フィルタを用いて参照フレームを 3×3 補間するか又は“アップサンプリング”する。この補間バージョンは、参照フレームの9倍のメモリを必要とする。1個の与えられたマクロブロックにおいて、Telenor符号化器は最適動きベクトルを2つのステップで推定する。即ち、符号化器は、先ず最適な整数ペルベクトルを探索し、次に V_1 に近い最適な $1/3$ 画素精度のベクトル $V_{1/3}$ を探索する。図1の例では、 3×3 補間参照フレーム内の（ 16×16 画素）の全8ブロックを調べ、図示のように動きベクトル $V_{1/3} = (VX, VY) = (1 + 1/3, 1)$ に関連するブロックである最も一致するブロックを見つけ出す。このTelenor符号化器は、幾つかの問題を有している。先ず、 $1/3$ ペル精度の動きベクトルを計算するために部分最適なファストサーチ戦略と複雑な立方体フィルタを（全段階において）使用することである。結果として、計算した動きベクトルは、最適ではなく、莫大な記憶容量と計算量を要し非常に高価につく。さらに、このTelenor符号化器は、 $1/3$ 画素に固定した有効レート歪み判定基準による精度を用い、そのために、より良い動き精度を選択するには適応できない。同様に、このTelenor符号化器の変長符号（“VLC”）テーブルは、 $1/3$ 画素に固定した精度を有しているので、異なる精度に対して適応できず異なる解釈ができない。

【0006】最も良く知られている動画圧縮方法では、 $1/2$ 画素精度で動きベクトルを推定して符号化するが、その理由は、従前の研究によれば、より高い又はより適応性を有する動き精度では計算が複雑になるだけで追加の圧縮利得が得られないことを示唆していたからである。しかしながら、これらの従前の研究は、最適化レート歪み判定基準を用いて動きベクトルを推定しておらず、計算の複雑化を減少させるためにかような基準の凸

状特性を利用しておらず、動きベクトルと動きベクトルの精度を符号化する有効な戦略を用いていなかった。

【0007】かような従前の研究の1つとして、Bernard Girodの論文（以後Girodの論文と略記する）“分数ペル精度による動き補償予測（Motion-Compensating Prediction with Fractional-Pel Accuracy）”（IEEE 通信会報，第41巻4号，604-612頁，1993年4月）が挙げられる。このGirodの論文は、動画符号化に部分画素（サブピクセル）の動き精度を用いる利点に関する最初の基本的な分析である。Girodは、部分画素空間における最適動きベクトルを探索するために簡単な階層戦略を用いた。彼はまた所与の精度に対する最適な動きベクトルを選択するために単純平均絶対差分（“MAD”）の基準を用いた。この最適精度は、理想化された仮定に基づくために非実用的な公式を用いて選択され、非常に複雑であり、また、全ての動きベクトルは1フレーム内の同一精度を持つものに制限される。最後に、Girodは、予測誤差エネルギーにのみ注目し、動きベクトルを符号化するためのビットの使用法には言及しなかった。

【0008】他の従前の研究として、Smita Gupta及びAllen Gershoの論文（以後“Guptaの論文”と略記する）“分数画素の動き推定（On Fractional Pixel Motion Estimation）”（SPIE VCI P会報，2094巻408-419頁，ケンブリッジ，1993年11月）が挙げられる。このGuptaの論文は、動画圧縮のために部分画素精度で動きベクトルを計算し選択して符号化する方法を提示している。Guptaの論文は、平均自乗誤差（“MSE”）と双線形補間に基づく公式を開示し、この公式を用いて理想的な動きベクトルを見つけ出し、かようなベクトルを所望の動き精度に量子化した。所与の精度に対する、この最適な動きベクトルは、部分最適MSE判定基準を用いて決定され、この最適精度は歪みビット当たりエネルギー差を最大限減少させる方法を用いて選択された。これは、渴望された（部分最適な）判定基準である。所与の動きベクトルの符号化は、最初に1/2ペル精度で符号化し、次に詳細化ビットでより高精度に符号化する方法で行われた。粗から微細への符号化は、かなりのビットを必要とするきらいがある。

【0009】論文“ブロックに基づく動き補償動画符号化器の場合の最適動きベクトル精度（On the Optimal Motion Vector Accuracy for Block-Based Motion-Compensated Video Coders）”（IST/SPIE デジタル動画の圧縮会報：アルゴリズムと技術，302-314頁，サンジョセ，1996年2月）（以後、Ribasの論文と略記する）において、Jordi Ribas-Corbera及びDavid L. Neuhoffは、動き精度のビットレートへの影響をモデル化し、ビットレートを最小にする最適精度を推定する幾つ

かの方法を提案した。このRibasの論文は、任意精度に対する動きベクトルを計算するためのフルサーチ方法を記述し、双線形補間のみを考慮した。最適な動きベクトルはMSEを最小にすることにより発見し、最適精度はレート歪みの最適化により導出された幾つかの公式を用いて選択した。動きベクトルと精度は、リアルタイム装置には実装が難しい、複雑なフレーム適応エントロピー符号化器を用いて符号化した。

【0010】論文“より高いビットレートでの予測強化に関する新しいコア実験の提案（Proposal for a new core experiment on Prediction enhancement at higher bitrates）”（ISO/IEC JTC1/SC29/WG11 動画及び音声の符号化、MPEG97/1827，セビリア，1997年2月）及び“1/4ペル動き補償のための複雑さを軽減した実装装置の性能評価（Performance Evaluation of a Reduced Complexity Implementation for Quarter Pel Motion Compensation）”（ISO/IEC JTC1/SC29/WG11 動画及び音声の符号化，MPEG97/3146，サンジョセ，1998年1月）において、Urich Benzlerは、動画シーケンスのために1/4ペル精度の動きベクトルの使用と、MPEG4動画符号化基準のさらに進んだ補間フィルタの使用を提案した。しかしながら、Benzlerは、1/4ペルの動きベクトルの発見にGirodのファストサーチ技法を用いた。Benzlerは、異なる補間フィルタを考慮しなかったが、第1段階で複合フィルタを使用して第2段階でより簡単なフィルタを使用することを提案し、一度に1つのマクロブロックを補間した。この方法は、多量のキャッシュメモリは必要としないが、複雑であり、全ての動きベクトルを1つのマクロブロック内の全ての可能なモード（例えば、16×16，4-8×8，16-4×4等）につき1/4ペル精度で計算して最適のモードを決定するために、計算量が多大である。BenzlerはMAD判定基準を使用して、全シーケンスに対し1/4ペル精度に固定した最適な動きベクトルを発見した。従って、最適な動き精度を選択する方法は示さなかった。最後に、Benzlerは、1/2及び1/4画素精度のベクトルを符号化するために使用可能な可変長符号（“VLC”）テーブルを用いて動きベクトルを符号化した。

【0011】

【発明が解決しようとする課題】上述の参考文献は、最適化したレート歪み基準を用いて動きベクトルを推定しておらず、かような基準の凸状特性を利用して計算の複雑さを軽減していない。さらに、これらの参考文献は、動きベクトルと精度を符号化する有効な戦略を用いていない。

【0012】

【課題を解決するための手段】本発明の1つの実施形態

は、高画素精度（“分数”又は“部分画素”精度とも称される）の動きベクトルを僅かな計算量の増加で計算することにより従来技術の問題を解決する。

【0013】本発明の戦略を用いると、動画符号化器はかなりの圧縮利得（例えば、動き精度の古典的な選択に比較して30%に達するビットレートの削減）を同等の計算レベルで達成できることが、実験により明らかになっている。動き精度に適応して計算し選択するので、本発明は適応動き精度（“AMA”）方式として記述できる。

【0014】本発明の好ましい実施形態の1つは、部分画素（サブピクセル）空間におけるファストサーチ戦略を用いて最適な動きベクトルをスマートにサーチする。この技法は、1マクロブロックに対する最適な動きベクトルを発見することにより、動き補償動画符号化時の動きベクトルを推定する。第1ステップは、 V_1 に中心をもつ予め定められた正方形範囲の部分画素解像度のグリッド内で、第1セットの動きベクトル候補をサーチして最適な動きベクトル V_2 を見つけ出す。次に、 V_2 に中心をもつ予め定められた正方形範囲の部分画素解像度をもつグリッド内で、第2セットの動きベクトル候補を探索して最適な動きベクトル V_3 を見つけ出す。その後、 V_3 に中心をもつ予め定められた正方形範囲の部分画素解像度をもつグリッド内で、第3セットの動きベクトル候補を探索してマクロブロックの最適動きベクトルを見つけ出す。

【0015】本発明の別の好ましい実施形態において、高精度の動きベクトル推定技法は異なる段階において異なる補間フィルタを使用して計算の複雑さを低減することができる。

【0016】本発明の別の好ましい実施形態は、レート歪み（RD）に関して最適のベクトルと精度を選択する。この実施形態は、異なる動き精度に従い対応するレート歪み判定基準を用いて最適な動きベクトルと最適な動き精度の両方を決定する。

【0017】本発明のさらに別の好ましい実施形態は、有効な可変長符号化（VLC）法により、動きベクトルと精度を符号化する。この技法は、異なる符号化単位で異なる解釈が可能な、関連する動きベクトル精度に従ったVLCテーブルを使用する。

【0018】本発明の上述及び他の目的、特徴及び利点は、添付図面を参照し本発明の以下の詳細な説明を読めば容易に理解されよう。

【0019】

【発明の実施の形態】本発明の諸方法は、各画像ブロックにおいて動き精度を変更して説明するが、精度を全シーケンスに対して固定又はフレーム毎に変更する場合にも適用できる。本発明は、又、発明の背景において記述したように、Telenorの動画符号化器（及び特殊にはTelenorの符号化器）を使用するものとして

記述する。Telenorの動画符号化器の用語を用いて説明するが、ここに記述する技術は、任意の他の動き補償動画符号化器にも適用できる。

【0020】動画符号化器の多くは、半画素（又は“ $1/2$ ペル”）精度の動きベクトルと双線形補間を用いる。Telenorの符号化器の第1バージョンは、 $1/2$ ペル動きベクトルと双線形補間を用いる。しかしながら、Telenorの符号化器の最新バージョンは、さらなる圧縮利得を得るために $1/3$ ペルベクトルと立方体形補間機能を内蔵している。特に、1つの与えられたマクロブロックにおいて、Telenorの符号化器は、図2に示す2つのステップで最適な動きベクトルを推定する。先ず、このTelenor符号化器は、最適な整数ペルベクトル V_1 （図1）を探索する（ステップ100）。次に、このTelenor符号化器は、 V_1 付近の最適な $1/3$ ペル精度ベクトル $V_{1/3}$ （図1）をサーチする（ステップ102）。この第2ステップは図1のグラフに示すように、 3×3 内挿（補間）参照フレーム内の（各々 16×16 の画素列を有する）全部で8個のブロックを調べて最も一致するブロックを見つけ出す。8個のブロックの動きベクトルは、 V_1 に中心をもつグリッド中に8個の実点で表示してある。図1において、最も一致するのは、動きベクトル $V_{1/3} = (V_x, V_y) = (1 + 1/3, 1)$ に関連するブロックである。

【0021】本発明の技術によれば、符号化器は、フルサーチ戦略又はファストサーチ戦略のいずれかを用いて任意の動き精度の組（例えば、 $1/2$ 、 $1/3$ 及び $1/6$ ペル精度動きベクトル）間で精度を選択できる。

【0022】（フルサーチAMA方式のサーチ戦略）図3及び図4に示すように、このフルサーチ適応動き精度（AMA）方式サーチ戦略の場合、Telenor符号化器は、図3に示す5個の画素の（上方画素数、下方画素数及び両側の画素数により規定される正方形ブロックとして定義される）“正方形範囲”と $1/6$ 画素解像度のグリッド上の全ての動きベクトル候補をサーチする。図4に示すように、フルサーチAMAの第1ステップ（104）では最適な整数ペルベクトル V_1 （図1）をサーチする。フルサーチAMAの第2ステップ（106）において、符号化器は V_1 付近の最適な $1/6$ 画素精度ベクトル $V_{1/6}$ （図3）をサーチする。換言すれば、このフルサーチAMAは、Telenorプロセスの第2ステップを変更して符号化器が速度空間内の他の部分画素位置における動きベクトル候補もサーチできるようにしたものである。この目的は、グリッド内の最適動きベクトル、即ち、現マクロブロックに最も一致するブロック（補間参照フレーム内）を指示するベクトルを発見することである。このフルサーチ戦略は、120個の部分画素候補をサーチするので計算は複雑ではあるが、本発明のこの実施形態の全潜在能力を示している。

【0023】動きベクトルサーチにおける重要な課題

は、所与のマクロブロックに最も符合するブロックを確定する判定測度又は基準の選択である。実際には、殆どの方法は、平均自乗誤差(MSE)又は平均絶対差分

(MAD)の何れかの判定基準を用いている。2つのブロック間のMSEは、2つのブロックの画素値を引き算して、画素値差を自乗し、平均値を取る。2つのブロック間のMAD差分は、自乗計算の代わりに画素値差の絶対値を計算することを除き同様な歪み測度である。2つの画像ブロックが互いに類似であれば、MSE及びMADの値は小さい。しかしながら、画像ブロックが類似でなければ、これらの値は大きい。従って、代表的な動画符号化器は、最小のMSE又は最小のMADの何れかをもちたす動きベクトルを選択することにより、マクロブロックに最も符合するマクロブロックを見つけ出す。言い換えれば、最適動きベクトルに関連するブロックは、MSE又はMADにおいて所与のマクロブロックに最も近似のブロックである。

【0024】残念ながら、MSE及びMADの歪み測度は、ベクトルを実際に符号化するビットのコストを考慮していない。例えば、1つの任意動きベクトルはMSEを最小にできるが、しかし、ビットで符号化するコストが非常に高く、符号化の観点から最適の選択でない場合があり得る。

【0025】この問題を処理するために、Telenorが記述しているような最新の符号化器は、“歪み+L×ビット”形のレート歪み(RD)判定基準を使用して最適な動きベクトルを選択する。“歪み”値は、代表的にはMSE又はMADであり、“L”は圧縮レベル(即ち、量子化ステップサイズ)に依存する定数であり、“ビット”は動きベクトルの符号化に要するビット数である。一般に、このタイプのどのRD判定基準も本発明に使用できる。しかしながら、本発明の場合、“ビット”は、ベクトルの符号化に要するビットとそのベクトル精度の符号化に要するビットを含んでいる。事実、幾つかの候補が、幾つかの精度モードをもつために、若干数の“ビット”値をもち得る。例えば、位置(1/2, -1/2)に在る候補は、1/2又は1/6画素精度をもつと考えられる。

【0026】(ファストサーチAMA方式サーチ戦略)図5及び図6に示すように、ファストサーチ適応動き精度(AMA)方式サーチ戦略の場合、符号化器は動きベクトル候補の小さいセットのみを調べる。ファストサーチAMAの第1ステップ(108)では、符号化器は、1/2画素解像度のグリッドにおいてV₁に中心をもち一辺が1の正方形(正方形範囲1内)の8個の動きベクトル候補をチェックする。最小のRDコストを有する候補(即ち、8個の前ベクトルとV₁の中で最適のもの)を表現するためにV₂を設定する(110)。次に、符号化器は、1/6画素解像度のグリッド上でV₂に中心をもち一辺が1の正方形内の8個の動きベクトル位置を

チェックする(112)。V₂が最小RDコストを有している場合(114)、符号化器は探索を中止し、V₂をブロックの動きベクトルとして選択する。そうでなければ、8個の前ベクトルの中で最適のものを表現するためにV₃を設定する(116)。符号化器は、次に1/6画素解像度のグリッドにおいてV₃に中心をもつ正方形範囲1内の新しい動きベクトル候補をサーチする(118)。このグリッド内の幾つかの候補は既にチェック済みであり飛ばすことができることに注意すべきである。この最終ステップでは最小のRDコストをもつ候補をブロックの動きベクトルとして選択する(120)。

【0027】実験データによれば、この簡単なファストサーチ戦略は、平均で(Telenor探索戦略より10個多い)部分画素空間における代表的な約18の位置のRDコストをチェックするので、従って、全体としての計算の複雑さは適度の増加に留まる。

【0028】図8乃至図18に関連して以下に説明する実験結果は、このAMA方式のファストサーチバージョンを用いることによる圧縮性能の損失が実際に皆無であることを示している。その理由は、このファストサーチAMA探索戦略が、RDコストが高レベルから低レベルにスマートに移行するパスを創設することによって“歪み+L×ビット”曲線の凸度(“歪み”は凸性であることは知られている)を活用しているからである。

【0029】本発明の別の実施態様は、ステップ108-120のうちの1つ又はそれ以上を変更する。これらの実施形態も効率的であり、部分画素速度空間においてチェックする動きベクトル候補数をさらに削減している。

【0030】図7の例では、1/3ペル精度の候補をチェックする。この実施例において、ステップ112は3つの可能なシナリオの1つで置き換えられる。まず、ステップ110からの最適な動きベクトル候補がV₁(“整数ペルベクトル”)の中心にあれば(130)、符号化器は中心ベクトルと次に最低のRDコストをもつ1/2ペル位置の間にある1/3ペル精度の3候補をチェックする(132)。次に、ステップ110からの最適な動きベクトル候補がコーナーのベクトルであれば(134)、符号化器はかようなコーナーベクトルに最も近い1/3ペル精度の4ベクトル候補をチェックする(136)。第3に、ステップ110からの最適な動きベクトル候補が2つのコーナーベクトルの間にあれば(138)、符号化器は2つのコーナーベクトルの中でRDコストが低い方を決定し、ステップ110からの最適な動きベクトル候補とかようなコーナーとの間の直線に最も近い1/3ペル精度の4ベクトル候補をチェックする(140)。V₂が中心に無く又コーナーベクトルでも無い場合は2つのコーナー間にある筈であり、このプロセスを実行する際にステップ138は不必要になることに注意すべきである。符号化器を1/3画素精度

の動きベクトルの探索に設定する場合、図7は、ステップ114への続行ではなく終了になるように変更可能である。

【0031】(計算量とメモリの削減)ステップ108では1/2画素精度の動きベクトル候補のみをチェックするために、ハードウェアとソフトウェアの実装に要する計算量とメモリは大幅に削減される。特に、このファストサーチのスマートな実装において、参照フレームは2×2だけ補間して1/2ペルベクトル候補に対するRDコストを得る。ハードウェア又はソフトウェア符号化器用のファスト(又はキャッシュ)メモリは、参照フレームを3×3だけ補間するために要するTelenorの方法と比較してかなりの量削減される。Telenorの符号化器と比較し、キャッシュメモリは9/4の削減又は2.25倍の削減になる。若干の追加補間はブロック単位で後で行うことができる。

【0032】さらに、ステップ108における補間はRDコスト関数値を下げる方向にサーチを方向づけるように用いるので、これらの補間には複合フィルタを必要としない。従って、計算量はステップ108用に簡単な双線形フィルタを用いることにより節減できる。

【0033】又、マクロブロックモード(例えば、16×16、4個の8×8等)の選択のような他の主要な符号化に関する決定は、そのような決定は高精度を用いることによる有意な利益がないので、1/2ペルベクトルを用いて行うことができる。次に、符号化器は残りのステップにおいてチェックする若干の追加ベクトル候補に対して必要な部分画素値を補間するためにより複雑な立方体(3次)フィルタを使用することができる。マクロ*

符号	動き精度
1	1/2ペル
01	1/3ペル
11	1/6ペル

表1. 所与のマクロブロックに対する精度モードを示す可変長(VLC)符号表

【0038】次に、各々の精度空間におけるベクトル値を符号化する。これらのビットはH26Lコーディックにおいて使用されるような単一VLCテーブルの項目より得ることができる。重要なアイデアは、これらのビットはマクロブロックの動き精度によって異なって解釈されることである。例えば、動き精度が1/3であり、異なる動きベクトルのX成分に対する符号ビットが000011である場合、ベクトルのX成分は $V_x = 2/3$ である。精度が1/2であれば、ベクトルのX成分は $V_x = 1$ に相当する。

【0039】1/2及び1/4画素精度ベクトルの符号化に使用できる可変長符号(VLC)テーブルにより動きベクトルを符号化するBenzlerの方法と比較して、本発明の方法は、任意の動き精度のベクトルを符号化するのに用いられ、テーブルは、各フレームとマクロ

*ブロックモードは既に選択済みであるので、これらの最後の補間は選択モードに対し実施する必要がある。

【0034】複数フィルタを使用することにより、常時立方体補間を用いるTelenorの方法と比較し、Sparc Ultra 10型ワークステーションでの稼動時間で20%を超える計算量の削減が得られた。さらに、ファストメモリの必要性は、略半分に減少した。又、圧縮性能に関しては損失は殆どなかった。このファストサーチの1実施形態での比較において、Benzler技法は、Telenor符号化器において画素当たり約70の補間を必要とするのに対し、本発明は画素当たり約7つの補間を要するのみである。

【0035】(動きベクトルと精度のビット符号化)最適な動きベクトルと精度が決定されると、符号化器は動きベクトルと精度値の両方をビットで符号化する。1つの方法は、所与の精度(例えば、半画素精度)で動きベクトルを符号化し、次に、そのベクトルをより高い動き精度に詳細化するために幾つかのエクストラビットを追加する。これは、B. Girodが提案した戦略であるが、但し、レート歪みの点では部分最適化である。

【0036】本発明の1つの好ましい実施形態では、1つのマクロブロックに対する動きベクトルの精度を表1に示したような簡単な符号を用いて最初に符号化する。符号長{1, 2, 2}の任意の他のテーブルを用いることも可能である。ビットレートは、代表的なDPCM法を用いてさらに減少させることができる。

【0037】

【表1】

ブロックにおいて異なって解釈できる。さらに、本発明の全体的方法は、任意の動き精度に適用でき、互いに倍数であったり $1/n$ (n は整数)型である必要はない。所与の部分画素空間における増分数は単純に計数し、テーブルの関連項目中のビットを符号として使用する。復号器の観点からは、動き精度を復号すれば動きベクトルもまた容易に復号することができる。その後、前フレーム中の関連ブロックを代表的な4タップの立方体補間器を用いて再構築する。各動き精度毎に異なる4タップフィルタが存在する。AMA方式は、予測ブロックの再構築に要する動作数は同じで、動き精度とは無関係なので、復号の複雑さを増大させることはない。

【0040】(実験結果)図8乃至図18は、表2に記載の種々の動画シーケンス、解像度及びフレームレートでAMAを使用又は使用せずにTelenorの符号化

コーディックを試験した結果を示している。これらの図面は、各ケース毎にレート歪み（“RD”）を作図したものである。“Anchor”曲線は、最適化H. 263+（図8と図9のみ）からのRD点を示している。“Telenor 1/2+b”曲線は1/2ペルベクトルと双線形補間によるTelenor（古典的な例）を示している。“Telenor 1/3”曲線は、現Telenorの提案（“Telenor符号化器”）を示している。“Telenor+AMA+c”曲線は、本発明のフルサーチ戦略によるTelenor符号化器を示している。図15乃至図17に示す“Telenor+F*

*SAMA+c”曲線は、本発明のファストサーチ戦略によるTelenor符号化器を示している。（他に規定がない限り、AMAのフルサーチバージョンは実験に使用した符号化器の戦略であった。）全ての試験結果は、符号化器と復号器においてクロスチェックを行った。これらの結果は、AMAを実施する場合、信号対雑音（ノイズ）比のピーク（“PSNR”）における利得は、H 26Lを超え1dBの高さであり、古典的な例よりもさらに高い。

【0041】

【表2】

ビデオシーケンス	図#	解像度	フレームレート
コンテナ	図 8	QCIF	10
ニュース	図 9	QCIF	10
自動車	図10	QCIF	10
	図11	SIF	15
庭園	図12	QCIF	15
Tempe te	図13	SIF	15
	図14	QCIF	15
ゆれるパリ	図15	QCIF	10

表2. 実験の説明

【0042】動画シーケンスは、“ゆれるパリ”を除き、動画符号化共同体により共通に使用されている。後者は、よく知られているシーケンス“パリ”を、XとY成分が[-1, 1]の範囲で任意の値をとる動きベクトルだけ移動させることにより得られた合成動画である。この合成動画は、代表的な動画電話シーンにおいて手持ちカメラにより生じた小さな動きをシミュレートする。

【0043】（動き精度適応（AMA）方式のフルサーチ及びファストサーチの比較）図16及び17に示した実験結果は、AMAに関するファストサーチ戦略（“Telenor FSAMA+c”）とフルサーチ戦略（“Telenor AMA+c”）方式の符号化器の使用性能が実際には同じであることを示している。ファストサーチ戦略は部分画素速度空間においてRDコスト曲線の凸性を利用するのでこれは間違いない。言い換えれば、RDコスト曲線の形状はなだらかな凸曲線を辿るので、その最小値は、曲線を下降させる幾つかのスマートなファストサーチスキームを用いて容易に見出される。

【0044】（AMA及び複数参照フレームの結合）図18に示すグラフにおいて、“1r”の標識をもつ曲線は、動き補償のために1枚の参照フレームのみを使用した。従って、これらの曲線は図10に示した曲線と同じである。“5r”の標識をもつ曲線は5枚の参照フレームを使用した。AMAによる利得は複数の参照フレームを使用して得た曲線に付加されることを実験は示している。参照フレーム1枚の場合のAMAによる利得は、緑とピンクの曲線（注：凡例で×と△）を比較することにより測定でき、参照フレーム5枚の場合の利得は青と赤

の曲線（注：凡例で○と●）間で測定できる。

【0045】特に注意すべきことは、本発明はフレームレベルで実施でき、異なるフレームは異なる動き精度を用いることができるが、1フレーム内の全ての動きベクトルには同一精度を用いることである。この実施形態において、動きベクトル精度は、フレーム層において1度だけ信号化されるのが好ましい。実験は、全フレームに対して最適な固定動き精度を用いることによって、マクロブロック適応の場合につき提示したような圧縮利得が生じることを示している。

【0046】他のフレームベースの実施形態において、符号化器は、異なるベクトル精度でフレーム全体に動き補償を行い、その後、RD判定基準に従って最適な精度を選択することができる。この方法は、パイプライン方式のワンパス符号化器には適しないが、ソフトウェアベースの符号化器又はより複雑な符号化には適用できる。他のフレームベースの実施形態において、符号化器は所与のフレームに対する最適精度を予測するために以前の統計値及び／又は公式を用いることができる（例えば、Ribasの論文に記述されている公式又はそのバージョンを使用することができる）。この方法は、性能利得は予測に用いる公式の精度に依存するが、ワンパス符号化器には適している。

【0047】上述の明細書に用いた用語と表現は説明のためのものであり制限するものではなく、かような用語と表現を用いるに当たって表示及び記述の特徴又はその部分の同等の用語及び表現を排除する意図は全くなく、本発明の範囲は特許請求範囲の請求項によってのみ規定

され限定されることを確認する。

【図面の簡単な説明】

【図1】速度空間における完全ペル及び1/3ペルの位置の例を示す図である。

【図2】最適動きベクトルを推定する従来技術による方法を説明するためのフローチャート図である。

【図3】部分画素速度空間におけるフルサーチ時の動きベクトル候補位置の例を示す図である。

【図4】本発明によるフルサーチ方式の最適動きベクトル推定方法の好ましい実施態様を説明するためのフローチャート図である。

【図5】部分画素速度空間におけるファストサーチ時の動きベクトル候補位置の例を示す図である。

【図6】本発明によるファストサーチ方式の最適動きベクトル推定方法の好ましい実施形態を説明するためのフローチャート図である。

【図7】図6のステップ114の別の好ましい実施形態を説明するためのフローチャート図である。

【図8】動画シーケンス“コンテナ”において每秒10フレームのフレームレートと解像度QCIFで適応動き精度(AMA)を使用、または使用しないでTelenor符号化器の性能試験をした結果を示すグラフ図である。

【図9】動画シーケンス“ニュース”において每秒10フレームのフレームレートと解像度QCIFで適応動き精度(AMA)を使用または使用しないでTelenor符号化器の性能試験をした結果を示すグラフ図である。

【図10】動画シーケンス“自動車”において每秒10フレームのフレームレートと解像度QCIFで適応動き精度(AMA)を使用または使用しないでTelenor符号化器の性能試験をした結果を示すグラフ図である。

【図11】動画“庭園”において毎秒15フレームのフレームレートと解像度SIFで適応動き精度(AMA)を使用または使用しないでTelenor符号化器*

*の性能試験をした結果を示すグラフ図である。

【図12】動画シーケンス“庭園”において毎秒15フレームのフレームレートと解像度QCIFで適応動き精度(AMA)を使用または使用しないでTelenor符号化器の性能試験をした結果を示すグラフ図である。

【図13】動画シーケンス“Tempete”において毎秒15フレームのフレームレートと解像度SIFで適応動き精度(AMA)を使用または使用しないでTelenor符号化器の性能試験をした結果を示すグラフ図である。

【図14】動画シーケンス“Tempete”において毎秒15フレームのフレームレートと解像度QCIFで適応動き精度(AMA)を使用または使用しないでTelenor符号化器の性能試験をした結果を示すグラフ図である。

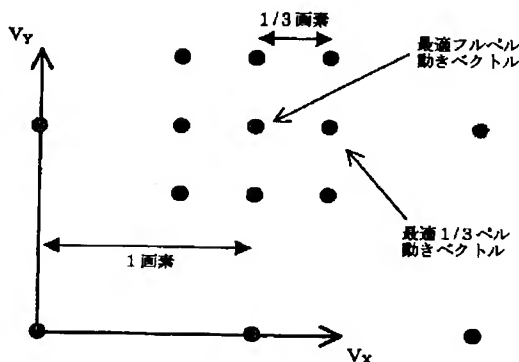
【図15】動画シーケンス“ゆれるパリ”において毎秒15フレームのフレームレートと解像度QCIFで適応動き精度(AMA)を使用または使用しないでTelenor符号化器の性能試験をした結果を示すグラフ図である。

【図16】動画シーケンス“自動車”において、毎秒10フレームのフレームレートと解像度QCIFでファストサーチ戦略(“Telenor FSAMA+c”)及びフルサーチ戦略(“Telenor AMA+c”)の性能試験の結果を示すグラフ図である。

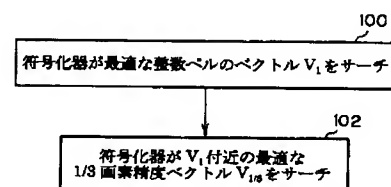
【図17】動画シーケンス“コンテナ”において毎秒10フレームのフレームレートと解像度QCIFでファストサーチ戦略(“Telenor FSAMA+c”)及びフルサーチ戦略(“Telenor AMA+c”)の性能試験の結果を示すグラフ図である。

【図18】動画シーケンス“自動車”において解像度QCIFと毎秒10フレームのフレームレートで動き補償のために1枚の参照フレームのみを使用し試験した場合と動き補償のために複数枚のフレームを使用し試験した場合とを比較する性能試験結果を示すグラフ図である。

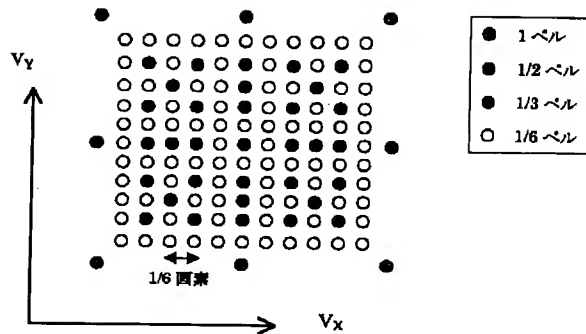
【図1】



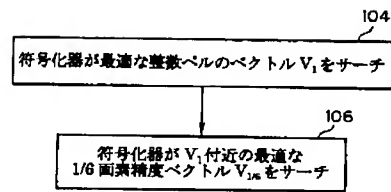
【図2】



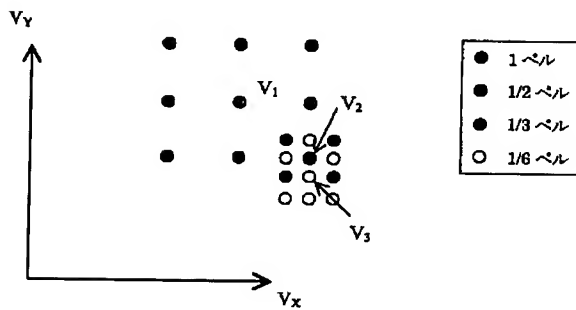
【図3】



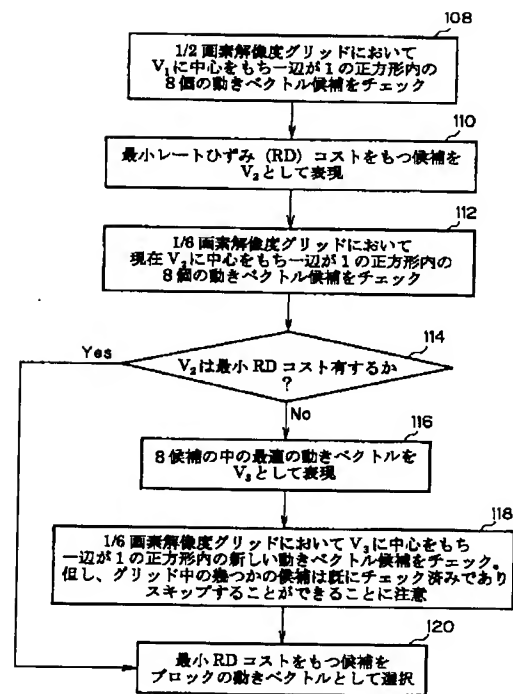
【図4】



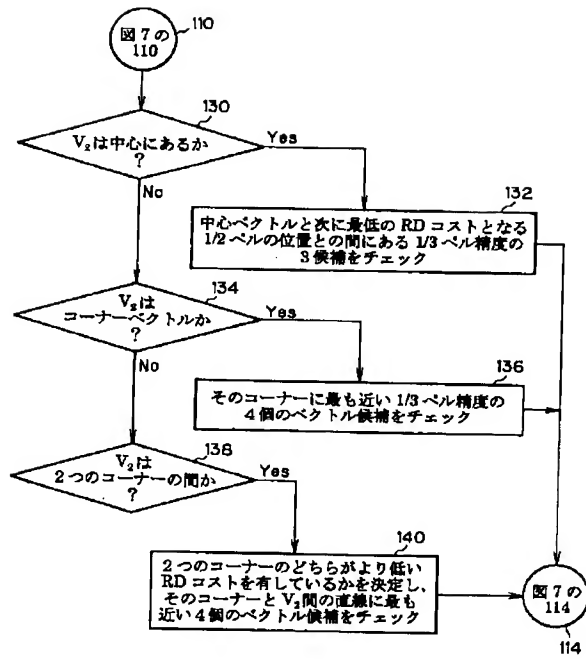
【図5】



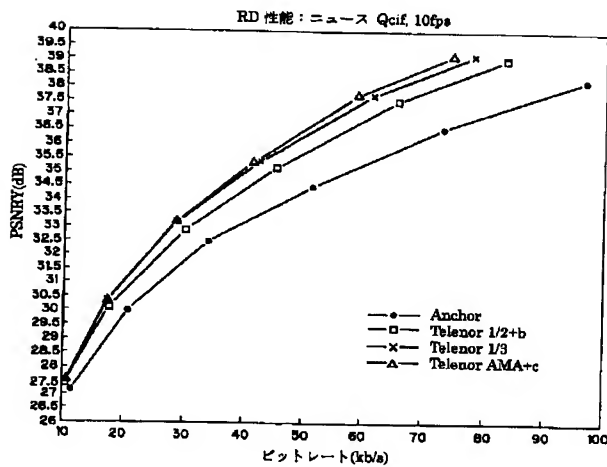
【図6】



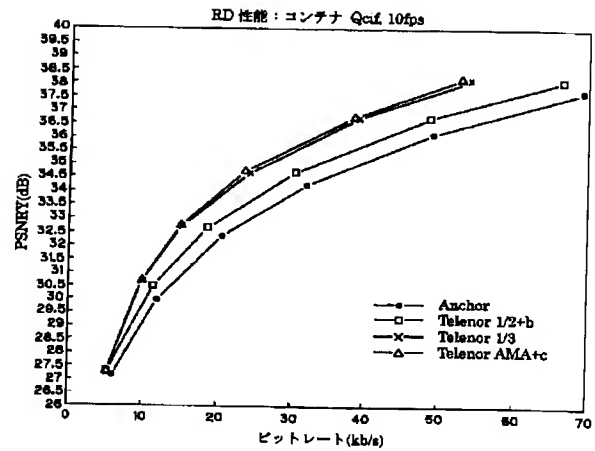
【図7】



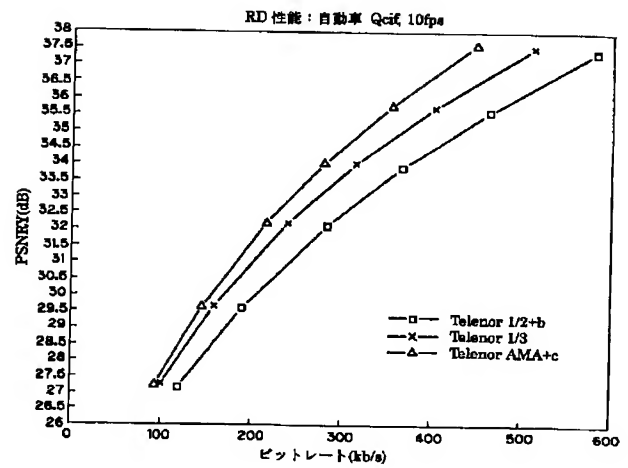
【図9】



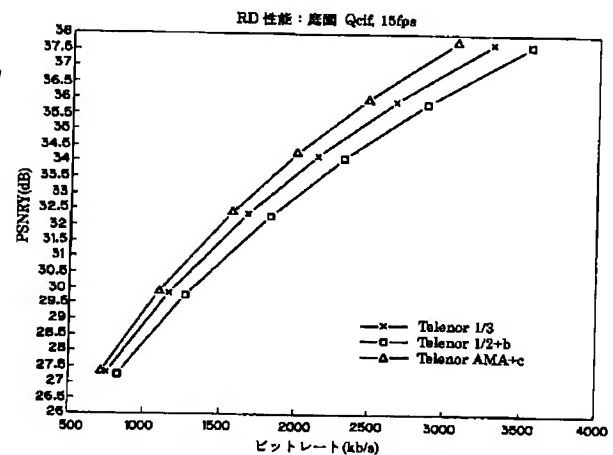
【図8】



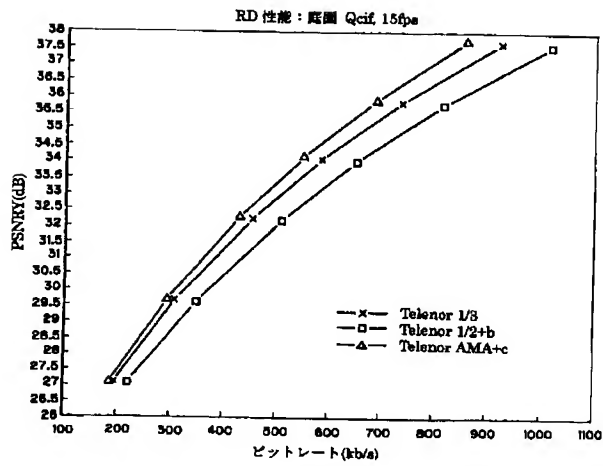
【図10】



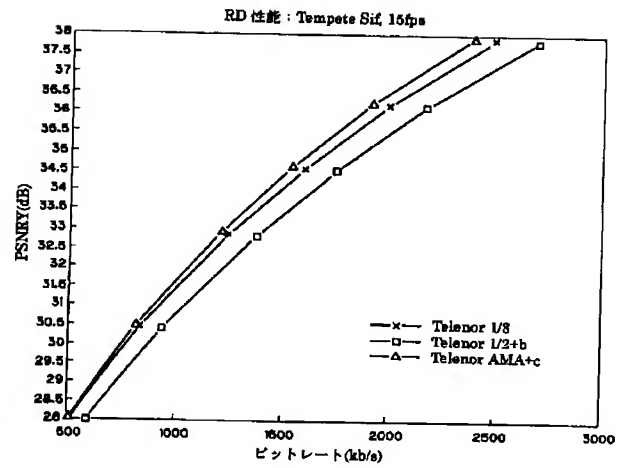
【図11】



【図12】

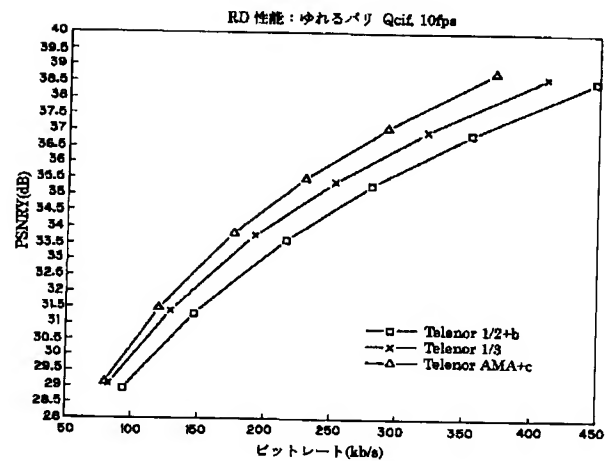
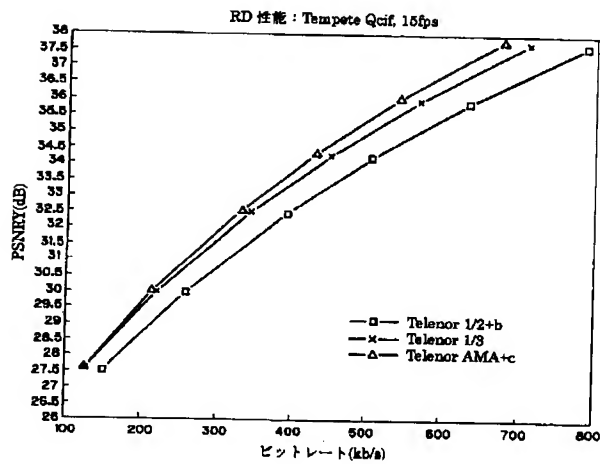


【図13】

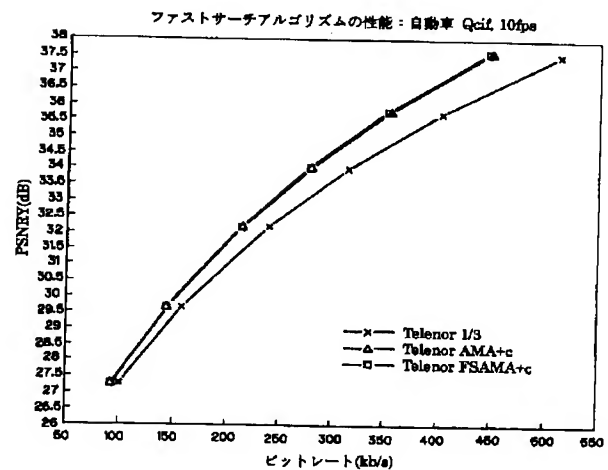


【図15】

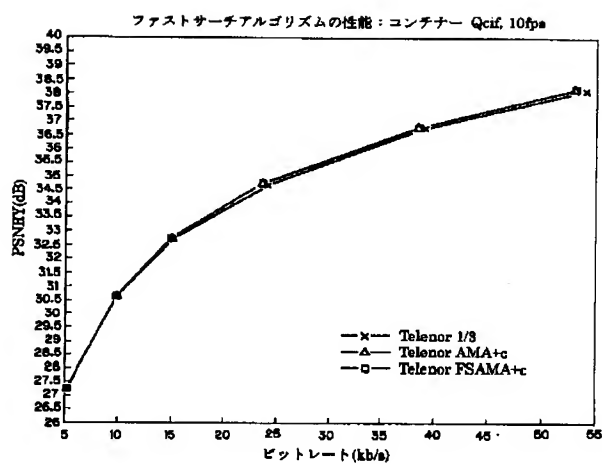
【図14】



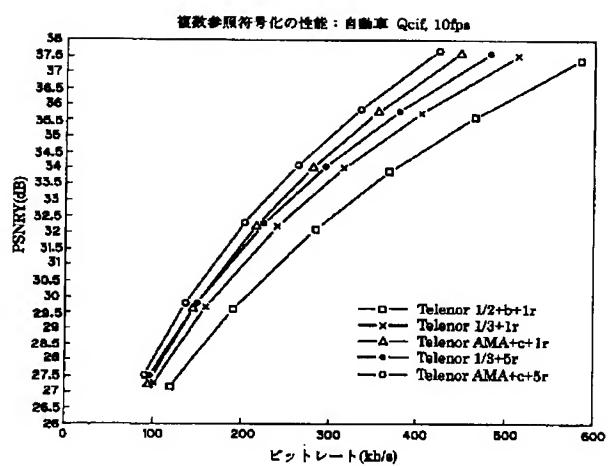
【図16】



【図17】



【図18】



【外国語明細書】

1. Title of Invention

METHODS FOR MOTION ESTIMATION WITH
ADAPTIVE MOTION ACCURACY

2. Claims

1. A fast-search adaptive motion accuracy search method for estimating motion vectors in motion-compensated video coding by finding a best motion vector for a macroblock, said method comprising the steps of:

- (a) searching a first set of motion vector candidates in a grid of sub-pixel resolution of a predetermined square radius centered on V_1 to find a best motion vector V_2 ;
- (b) searching a second set of motion vector candidates in a grid of sub-pixel resolution of a predetermined square radius centered on V_2 to find a best motion vector V_3 ; and
- (c) searching a third set of motion vector candidates in a grid of sub-pixel resolution of a predetermined square radius centered on V_3 to find said best motion vector of said macroblock.

2. The method of claim 1, said step of searching a first set of motion vector candidates in a grid of sub-pixel resolution of a predetermined square radius centered on V_1 to find a best motion vector V_2 further comprising the step of searching a first set of eight motion vector candidates in a grid of 1/2-pixel resolution of square radius 1 centered on V_1 to find a best motion vector V_2 .

3. The method of claim 1, said step of searching a second set of motion vector candidates in a grid of sub-pixel resolution of a predetermined square radius centered on V_2 to find a best motion vector V_3 further comprising the step of searching a second set of eight motion vector candidates in a grid of 1/6-pixel resolution of square radius 1 centered on V_2 to find a best motion vector V_3 .

4. The method of claim 1 further comprising the steps of using V_2 as the motion vector for the block if V_2 has the smallest rate-distortion cost and skipping step (c) of claim 1.

5. The method of claim 1, said step of searching a third set of motion vector candidates in a grid of sub-pixel resolution of a predetermined square radius centered on V_3 to find said best motion vector of said macroblock further comprising the step of searching a third set of eight motion vector candidates in a grid of 1/6-pixel resolution of square radius 1 centered on V_3 to find said best motion vector of said macroblock.

6. The method of claim 1, said step of searching a third set of motion vector candidates in a grid of sub-pixel resolution of a predetermined square radius centered on V_3 to find said best motion vector of said macroblock further comprising the step of skipping motion vector candidates of said third set of motion vector candidates that have already been tested.

7. The method of claim 1 further wherein said step of searching said first set of motion vector candidates further comprises the step of searching said first set of motion vector candidates using a first filter to do a first interpolation, said step of searching said second set of motion vector candidates further comprises the step of searching said second set of motion vector candidates using a second filter to do a second interpolation, and said step of searching said third set of motion vector candidates further comprises the step of searching said third set of motion vector candidates using a third filter to do a third interpolation.

8. The method of claim 1, said step of searching a second set of motion vector candidates in a grid of sub-pixel resolution of a predetermined square radius centered on V_2 to find a best motion vector V_3 further comprising the steps of:

- (a) searching three candidates of 1/3-pel accuracy V_2 and a 1/2-pel location with the next lowest RD cost if V_2 is at the center;
- (b) searching four vector candidates of 1/3-pel accuracy that are closest to V_2 if V_2 is a corner vector; and

- (c) determining which of two corners has lower RD cost and searching four vector candidates of 1/3-pel accuracy that are closest to a line between said corner with lower RD cost, if V_2 is between two corners vectors.

9. An adaptive motion accuracy search method for estimating motion vectors in motion-compensated video coding by finding a best motion vector for a macroblock, said method comprising the steps of:

- (a) searching a first set of motion vector candidates in a grid centered on V_1 to find a best motion vector V_2 using a first filter to do a first interpolation;
- (b) searching a second set of motion vector candidates in a grid centered on V_2 to find a best motion vector V_3 using a second filter to do a second interpolation; and
- (c) searching a third set of motion vector candidates in a grid centered on V_3 to find said best motion vector of said macroblock using a third filter to do a third interpolation.

10. The method of claim 9 wherein said step of searching using a first filter to do a first interpolation further comprises using a simple filter to do a coarse interpolation.

11. The method of claim 9 wherein said step of searching using a first filter to do a first interpolation further comprises using a simple filter to do a coarse interpolation and said step of searching using a second filter to do a second interpolation further comprises using a complex filter to do a fine interpolation.

12. The method of claim 11 wherein said step of searching using a third filter to do a third interpolation further comprises using a complex filter to do a fine interpolation.

13. The method of claim 9 wherein said step of searching using a first filter to do a first interpolation further comprises using a bilinear filter to interpolate the reference frame by 2x2.

14. The method of claim 9 wherein said step of searching using a first filter to do a first interpolation further comprises using a bilinear filter to interpolate the reference frame by 2x2 and said step of searching using a second filter to do a second interpolation further comprises using a cubic filter to do a fine interpolation.

15. The method of claim 14 wherein said step of searching using a third filter to do a third interpolation further comprises using a cubic filter to do a fine interpolation.

16. An adaptive motion accuracy search method for estimating motion vectors in motion-compensated video coding by finding a best motion vector for a macroblock, said method comprising the steps of:

- (a) searching at a first motion accuracy for a first best motion vector of said macroblock;
- (b) encoding said first best motion vector and said first motion accuracy;
- (c) searching for at least one second best motion vector of said macroblock at an at least one second motion accuracy;
- (d) encoding said at least one second best motion vector and said at least one second motion accuracy; and
- (e) selecting the best motion vector of said first and at least one best motion vectors using rate-distortion criteria.

17. The method of claim 16 wherein said step of selecting the best motion vector using rate-distortion criteria further comprises the step of said rate-distortion criteria adapting according to the different motion accuracies to determine both the best motion vectors and the best motion accuracies.
18. The method of claim 16, said step of searching for at least one second best motion vector at an at least one second motion accuracy further comprising the step of searching for at least one second best motion vector of said macroblock at an at least one second motion accuracy that is finer than said first motion accuracy.
19. The method of claim 16 wherein said step of selecting the best motion vector using rate-distortion criteria further comprises the step of using rate-distortion criteria of the type "distortion + L*Bits" to select the best motion vector.
20. An adaptive motion accuracy search method for estimating motion vectors in motion-compensated video coding by finding a best motion vector for a macroblock, said method comprising the steps of:
- (a) searching at a motion accuracy for a best motion vector of said macroblock;
 - (b) encoding said motion accuracy using a code from a VLC table that is interpreted differently at different coding units according to the associated motion vector accuracy; and
 - (c) encoding said best motion vector in the respective accuracy space.
21. A system for estimating motion vectors in motion-compensated video coding by finding a best motion vector for a macroblock, said system comprising:

- (a) a first encoder for searching a first set of motion vector candidates in a grid of sub-pixel resolution of a predetermined square radius centered on V_1 to find a best motion vector V_2 ;
- (b) a second encoder for searching a second set of motion vector candidates in a grid of sub-pixel resolution of a predetermined square radius centered on V_2 to find a best motion vector V_3 ; and
- (c) a third encoder for searching a third set of motion vector candidates in a grid of sub-pixel resolution of a predetermined square radius centered on V_3 to find said best motion vector of said macroblock.

22. The system of claim 21 wherein said first, second, and third encoders are a single encoder.

3. Detailed Description of Invention

BACKGROUND OF THE INVENTION

The present invention relates generally to a method of compressing or coding digital video with bits and, specifically, to an effective method for estimating and encoding motion vectors in motion-compensated video coding.

In classical motion estimation the current frame to be encoded is decomposed into image blocks of the same size, typically blocks of 16x16 pixels, called "macroblocks." For each current macroblock, the encoder searches for the block in a previously encoded frame (the "reference frame") that best matches the current macroblock. The coordinate shift between a current macroblock and its best match in the reference frame is represented by a two-dimensional vector (the "motion vector") of the macroblock. Each component of the motion vector is measured in pixel units.

For example, if the best match for a current macroblock happens to be at the same location, as is the typical case in stationary background, the motion vector for the current macroblock is (0,0). If the best match is found two pixels to the right and

three pixels up from the coordinates of the current macroblock, the motion vector is (2,3). Such motion vectors are said to have integer pixel (or "integer-pel" or "full-pel") accuracy, since their horizontal X and vertical Y components are integer pixel values. In FIG. 1, the vector $V_1 = (1,1)$ represents the full-pel motion vector for a given current macroblock.

Moving objects in a video scene do not move in integer pixel increments from frame to frame. True motion can take any real value along the X and Y directions. Consequently, a better match for a current macroblock can often be found by interpolating the previous frame by a factor NxN and then searching for the best match in the interpolated frame. The motion vectors can then take values in increments of 1/N pixel along X and Y and are said to have 1/N pixel (or "1/N-pel") accuracy.

In "Response to Call for Proposals for H.26L," ITU-Telecommunications Standardization Sector, Q.15/SG16, doc. Q15-F-11, Seoul, Nov. 98, and "Enhancement of the Telenor proposal for H.26L," ITU-Telecommunications Standardization Sector, Q.15/SG16, doc. Q15-G-25, Monterey, Feb. 99, Gisle Bjontegaard proposed using 1/3-pel accurate motion vectors and cubic-like interpolation for the H26L video coding standard (the "Telenor encoder"). To do this, the Telenor encoder interpolates or "up-samples" the reference frame by 3x3 using a cubic-like interpolation filter. This interpolated version requires nine times more memory than the reference frame. At a given macroblock, the Telenor encoder estimates the best motion vector in two steps: the encoder first searches for the best integer-pel vector and then the Telenor encoder searches for the best 1/3-pixel accurate vector $V_{1/3}$ near V_1 . Using FIG. 1 as an example, a total of eight blocks (of 16x16 pixels) in the 3x3 interpolated reference frame are checked to find the best match which, as shown is the block associated to the motion vector $V_{1/3} = (VX, VY) = (1+1/3, 1)$. The Telenor encoder has several problems. First, it uses a sub-optimal fast-search strategy and a complex cubic filter (at all stages) to compute the 1/3-pel accurate motion vectors. As a result, the computed motion vectors are not optimal and the memory and computation requirements are very expensive. Further, the Telenor encoder uses an accuracy of the effective rate-distortion criteria that is fixed at 1/3-pixel and, therefore, does not adapt to select better motion accuracies.

Similarly, the Telenor encoder variable-length code ("VLC") table has an accuracy fixed at 1/3-pixel and, therefore, is not adapted and interpreted differently for different accuracies.

Most known video compression methods estimate and encode motion vectors with 1/2-pixel accuracy, because early studies suggested that higher or adaptive motion accuracies would increase computational complexity without providing additional compression gains. These early studies, however, did not estimate the motion vectors using optimized rate-distortion criteria, did not exploit the convexity properties of such criteria to reduce computational complexity, and did not use effective strategies to encode the motion vectors and their accuracies.

One such early study was Bernd Girod's "Motion-Compensating Prediction with Fractional-Pel Accuracy," IEEE Transactions on Communications, Vol. 41, No. 4, pp. 604-612, April 1993 (the "Girod work"). The Girod work is the first fundamental analysis on the benefits of using sub-pixel motion accuracy for video coding. Girod used a simple, hierarchical strategy to search for the best motion vector in sub-pixel space. He also used simple mean absolute difference ("MAD") criteria to select the best motion vector for a given accuracy. The best accuracy was selected using a formula that is not useful in practice since it is based on idealized assumptions, is very complex, and restricts all motion vectors to have the same accuracy within a frame. Finally, Girod focused only on prediction error energy and did not address how to use bits to encode the motion vectors.

Another early study was Smita Gupta's and Allen Gersho's "On Fractional Pixel Motion Estimation," Proc. SPIE VCIP, Vol. 2094, pp. 408-419, Cambridge, November 1993 (the "Gupta work"). The Gupta work presented a method for computing, selecting, and encoding motion vectors with sub-pixel accuracy for video compression. The Gupta work disclosed a formula based on mean squared error ("MSE") and bilinear interpolation, used this formula to find an ideal motion vector, and then quantized such vector to the desired motion accuracy. The best motion vector for a given accuracy was found using the sub-optimal MSE criteria and the best accuracy was selected using the largest decrease in difference energy per distortion bit, which is a greedy (sub-optimal)

criteria. A given motion vector was coded by first encoding that vector with 1/2-pel accuracy and then encoding the higher accuracy with refinement bits. Course-to-fine coding tends to require significant bit overhead.

In "On the Optimal Motion Vector Accuracy for Block-Based Motion-Compensated Video Coders," Proc. IST/SPIE Digital Video Compression: Algorithms and Technologies, pp. 302-314, San Jose, February 1996 (the "Ribas work"), Jordi Ribas-Corbera and David L. Neuhoff, modeled the effect of motion accuracy on bit rate and proposed several methods to estimate the optimal accuracies that minimize bit rate. The Ribas work set forth a full-search approach for computing motion vectors for a given accuracy and considered only bilinear interpolation. The best motion vector was found by minimizing MSE and the best accuracy was selected using some formulas derived from a rate-distortion optimization. The motion vectors and accuracies were encoded with frame-adaptive entropy coders, which are complex to implement in real-time applications.

In "Proposal for a new core experiment on prediction enhancement at higher bitrates," ISO/IEC JTC1/SC29/WG11 Coding of Moving Pictures and Audio, MPEG 97/1827, Sevilla, Feb. 1997 and "Performance Evaluation of a Reduced Complexity Implementation for Quarter Pel Motion Compensation," ISO/IEC JTC1/SC29/WG11 Coding of Moving Pictures and Audio, MPEG 97/3146, San Jose, Jan. 1998, Ulrich Benzler proposed using 1/4-pel accurate motion vectors for the video sequence and more advanced interpolation filters for the MPEG4 video coding standard. Benzler, however, used the Girod's fast-search technique to find the 1/4-pel motion vectors. Benzler did consider different interpolation filters, but proposed a complex filter at the first stage and a simpler filter at the second stage and interpolated one macroblock at a time. This approach does not require much cache memory, but it is computationally expensive because of its complexity and because all motion vectors are computed with 1/4-pel accuracy for all the possible modes in a macroblock (e.g., 16x16, four-8x8, sixteen-4x4, etc.) and then the best mode is determined. Benzler used the MAD criteria to find the best motion vector which was fixed to 1/4-pel accuracy for the whole sequence, and hence he did not address how to select the best motion accuracy. Finally,

Benzler encoded the motion vectors with a variable-length code ("VLC") table that could be used for encoding 1/2 and 1/4 pixel accurate vectors.

The references discussed above do not estimate the motion vectors using optimized rate-distortion criteria and do not exploit the convexity properties of such criteria to reduce computational complexity. Further, these references do not use effective strategies to encode motion vectors and their accuracies.

BRIEF SUMMARY OF THE INVENTION

One preferred embodiment of the present invention addresses the problems of the prior art by computing motion vectors of high pixel accuracy (also denoted as "fractional" or "sub-pixel" accuracy) with a minor increase in computation.

Experiments have demonstrated that, by using the search strategy of the present invention, a video encoder can achieve significant compression gains (e.g., up to thirty percent in bit rate savings over the classical choices of motion accuracy) using similar levels of computation. Since the motion accuracies are adaptively computed and selected, the present invention may be described as adaptive motion accuracy ("AMA").

One preferred embodiment of the present invention uses fast-search strategies in sub-pixel space that smartly searches for the best motion vectors. This technique estimates motion vectors in motion-compensated video coding by finding a best motion vector for a macroblock. The first step is searching a first set of motion vector candidates in a grid of sub-pixel resolution of a predetermined square radius centered on V_1 to find a best motion vector V_2 . Next, a second set of motion vector candidates in a grid of sub-pixel resolution of a predetermined square radius centered on V_2 is searched to find a best motion vector V_3 . Then, a third set of motion vector candidates in a grid of sub-pixel resolution of a predetermined square radius centered on V_3 is searched to find the best motion vector of the macroblock.

In an alternate preferred embodiment the present invention a technique for estimating high-accurate motion vectors may use different interpolation filters at different stages in order to reduce computational complexity.

Another alternate preferred embodiment of the present invention selects the best vectors and accuracies in a rate-distortion ("RD") sense. This embodiment uses

rate-distortion criteria that adapts according to the different motion accuracies to determine both the best motion vectors and the best motion accuracies.

Still further, another alternate preferred embodiment of the present invention encodes the motion vector and accuracies with an effective VLC approach. This technique uses a VLC table that is interpreted differently at different coding units, according to the associated motion vector accuracy.

The foregoing and other objectives, features, and advantages of the invention will be more readily understood upon consideration of the following detailed description of the invention, taken in conjunction with the accompanying drawings.

DETAILED DESCRIPTION OF THE INVENTION

The methods of the present invention are described herein in terms of the motion accuracy being modified at each image block. These methods, however, may be applied when the accuracy is fixed for the whole sequence or modified on a frame-by-frame basis. The present invention is also described as using Telenor's video encoders (and particularly the Telenor encoder) as described in the Background of the Invention. Although described in terms of Telenor's video encoders, the techniques described herein are applicable to any other motion-compensated video coder.

Most video coders use motion vectors with half pixel (or "1/2-pel") accuracy and bilinear interpolation. The first version of Telenor's encoder also used 1/2-pel motion vectors and bilinear interpolation. The latest version of Telenor's encoder, however, incorporated 1/3-pel vectors and cubic-like interpolation because of the additional compression gains. Specifically, at a given macroblock, Telenor's estimates the best motion vector in two steps shown in FIG. 2. First, the Telenor encoder searches for the best integer-pel vector V_1 (FIG. 1) 100. Second, the Telenor encoder searches for the best 1/3-pixel accurate vector $V_{1/3}$ (FIG. 1) near V_1 102. This second step is shown graphically in FIG. 1 where a total of eight blocks (each having an array of 16x16 pixels) in the 3x3 interpolated reference frame are checked to find the best match. The motion vectors for these eight blocks are represented by the eight solid dots in the grid centered on V_1 . In FIG. 1 the best match is the block associated to the motion vector $V_{1/3} = (V_x, V_y) = (1+1/3, 1)$.

The technology of the present invention allows the encoder to choose between any set of motion accuracies (for example, 1/2, 1/3, and 1/6-pel accurate motion vectors) using either a full search strategy or a fast search strategy.

Full-Search AMA Search Strategy

As shown in FIGS. 3 and 4, in the full-search adaptive motion accuracy ("AMA") search strategy the encoder searches all the motion vector candidates in a grid of 1/6-pixel resolution and a "square radius" (defined herein as a square block defined by a number of pixels up, a number of pixels down, and a number of pixels to both sides) of five pixels as shown in FIG. 3. FIG. 4 shows that the first step of the full-search AMA is to search for the best integer-pel vector V_1 (FIG. 1) 104. In the second step of the full-search AMA, the encoder searches for the best 1/6-pixel accurate vector $V_{1/6}$ (FIG. 3) near V_1 106. In other words, the full-search AMA modifies the second step of the Telenor's process so that the encoder also searches for motion vector candidates in other sub-pixel locations in the velocity space. The objective is to find the best motion vector in the grid, i.e., the vector that points to the block (in the interpolated reference frame) that best matches the current macroblock. Although the full-search strategy is computationally complex since it searches 120 sub-pixel candidates, it shows the full potential of this preferred method of the present invention.

A critical issue in the motion vector search is the choice of a measure or criterion for establishing which block is the best match for the given macroblock. In practice, most methods use either the mean squared error ("MSE") or mean absolute difference ("MAD") criteria. The MSE between two blocks consists of subtracting the pixel values of the two blocks, squaring the pixel differences, and then taking the average. The MAD difference between two blocks is a similar distortion measure, except that the absolute value of the pixel differences is computed instead of the squares. If two image blocks are similar to each other, the MSE and MAD values will be small. If, however, the image blocks are dissimilar, these values will be large. Hence, typical video coders find the best match for a macroblock by selecting the motion vector that produces either the smallest MSE or the smallest MAD. In other words, the block associated to the best motion vector is the one closest to the given macroblock in an MSE or MAD sense.

Unfortunately, the MSE and MAD distortion measures do not take into account the cost in bits of actually encoding the vector. For example, a given motion

vector may minimize the MSE, but it may be very costly to encode with bits, so it may not be the best choice from an coding standpoint.

To deal with this, advanced encoders such as those described by Telenor use rate-distortion ("RD") criteria of the type "distortion + L*Bits" to select the best motion vector. The value of "distortion" is typically the MSE or MAD, "L" is a constant that depends on the compression level (i.e., the quantization step size), and "Bits" is the number of bits required to code the motion vector. In general, any RD criteria of this type would work with the present invention. However, in the present invention "Bits" include the bits needed for encoding the vector and those for encoding the accuracy of the vector. In fact, some candidates can have several "Bits" values, because they can have several accuracy modes. For example, the candidate at location $(1/2, -1/2)$ can be thought of having $1/2$ or $1/6$ pixel accuracy.

Fast-Search AMA Search Strategy

As shown in FIGS. 5 and 6, in the fast-search adaptive motion accuracy ("AMA") search strategy the encoder checks only a small set of the motion vector candidates. In the first step of the fast-search AMA, the encoder checks the eight motion vector candidates in a grid of $1/2$ -pixel resolution of square radius 1, which is centered on V_1 108. V_2 is then set to denote the candidate that has the smallest RD cost (i.e., the best of the eight previous vectors and V_1) 110. Next, the encoder checks the eight motion vector locations in a grid of $1/6$ -pixel resolution of square radius 1 that is now centered on V_2 112. If V_2 has the smallest RD cost 114, the encoder stops its search and selects V_2 as the motion vector for the block. Otherwise, V_3 is set to denote the best motion vector of the eight 116. The encoder then searches for a new motion vector candidates in the grid of $1/6$ -pixel resolution of square radius 1 that is centered on V_3 118. It should be noted that some of the candidates in this grid have already been tested and can be skipped. The candidate with the smallest RD cost in this last step is selected as the motion vector for the block 120.

Experimental data has shown that, on average, this simple fast search strategy typically checks the RD cost of about eighteen locations in sub-pixel space (ten more than

Telenor's search strategy), and hence the overall computational complexity is only moderately increased.

The experimental data discussed below in connection with FIGS. 8-18 show that there is practically no loss in compression performance from using this fast-search version of AMA. This is because the fast-search AMA search strategy exploits the convexity of the "distortion + L*Bits" curve (c.f., "distortion" is known to be convex), by creating a path that smartly follows the RD cost from higher to lower levels.

Alternate embodiments of the invention replace one or more of the steps 108-120. These embodiments have also been effective and have further reduced the number of motion vector candidates to check in the sub-pixel velocity space.

FIG. 7, for example, checks candidates of 1/3-pel accuracy. In this embodiment step 112 is replaced by one of three possible scenarios. First, if the best motion vector candidate from step 110 is at the center of V_1 (the "integer-pel vector") 130, then the encoder checks three candidates of 1/3-pel accuracy between the center vector and the 1/2-pel location with the next lowest RD cost 132. Second, if the best motion vector candidate from step 110 is a corner vector 134, then, the encoder checks the four vector candidates of 1/3-pel accuracy that are closest to such corner 136. Third, if the best motion vector candidate from step 110 is between two corners 138, then, the encoder determines which of these two corners has lower RD cost and checks the four vector candidates of 1/3-pel accuracy that are closest to the line between such corner and the best candidate from step 110 140. It should be noted that in implementing this process step 138 may be unnecessary because if V_2 is neither at the center or a corner vector, then it would necessarily be between two corners. If the encoder is set to find motion vectors with 1/3-pixel accuracy, FIG. 7 could be modified to end rather than continuing with step 114.

Computation And Memory Savings

Because step 108 checks only motion vector candidates of 1/2-pixel accuracy, the computation and memory requirements for the hardware or software implementation are significantly reduced. To be specific, in a smart implementation

embodiment of this fast-search the reference frame is interpolated by 2x2 in order to obtain the RD costs for the 1/2-pel vector candidates. A significant amount of fast (or cache) memory for a hardware or software encoder is saved as compared to Telenor's approach that needed to interpolate the reference frame by 3x3. In comparison to the Telenor encoder, this is a cache memory savings of 9/4 or a factor of 2.25. The few additional interpolations can be done later on a block-by-block basis.

Additionally, since the interpolations in step 108 are used to direct the search towards the lower values of the RD cost function, a complex filter is not needed for these interpolations. Accordingly, computation power may be saved by using a simple bilinear filter for step 108.

Also, other key coding decisions such as selecting the mode of a macroblock (e.g., 16x16, four-8x8, etc.) can be done using the 1/2-pel vectors because such decisions do not benefit significantly from using higher accuracies. Then, the encoder can use a more complex cubic filter to interpolate the required sub-pixel values for the few additional vector candidates to check in the remaining steps. Since the macroblock mode has already been chosen, these final interpolations only need to be done for the chosen mode.

Use of multiple-filters obtained computation savings of over twenty percent in running time on a Sparc Ultra 10 Workstation in comparison to Telenor's approach, which uses a cubic interpolation all the time. Additionally, the fast-memory requirements were reduced by nearly half. Also, there was little or no loss in compression performance. Comparing one preferred embodiment of the fast-search, Benzler's technique requires about 70 interpolations per pixel in the Telenor encoder and the present invention requires only about 7 interpolations per pixel.

Coding The Motion Vector And Accuracies With Bits

Once the best motion vector and accuracy are determined, the encoder encodes both the motion vector and accuracy values with bits. One approach is to encode the motion vector with a given accuracy (e.g., half-pixel accuracy) and then add some extra

bits for refining the vector to the higher motion accuracy. This is the strategy suggested by B. Girod, but it is sub-optimal in a rate-distortion sense.

In one preferred embodiment of the present invention, the accuracy of the motion vector for a macroblock is first encoded using a simple code such as the one given in Table 1. Any other table with code lengths {1, 2, 2} could be used as well. The bit rate could be further reduced using a typical DPCM approach.

Code	Motion Accuracy
1	1/2-pel
01	1/3-pel
11	1/6-pel

Table 1. VLC table to indicate the accuracy mode for a given macroblock.

Next, the value of the vector/s in the respective accuracy space is encoded. These bits can be obtained from entries of a single VLC table such as the one used in the H26L codec. The key idea is that these bits are interpreted differently depending on the motion accuracy for the macroblock. For example, if the motion accuracy is 1/3 and the code bits for the X component of the difference motion vector are 000011, the X component of the vector is $V_x = 2/3$. If the accuracy is 1/2, such code corresponds to $V_x = 1$.

Compared to the Benzler method for encoding the motion vectors with a variable length code ("VLC") table that could be used for encoding 1/2 and 1/4 pixel accurate vectors, the method of the present invention can be used for encoding vectors of any motion accuracy and the table can be interpreted differently at each frame and macroblock. Further, the general method of the present invention can be used for any motion accuracy, not necessarily those that are multiples of each other or those that are of the type $1/n$ (with n an integer). The number of increments in the given sub-pixel space is simply counted and the bits in the associated entry of the table is used as the code.

From the decoder's viewpoint, once the motion accuracy is decoded, the motion vector can also be easily decoded. After that, the associated block in the previous frame is reconstructed using a typical 4-tap cubic interpolator. There is a different 4-tap filter for each motion accuracy.

The AMA does not increase decoding complexity, because the number of operations needed to reconstruct the predicted block are the same, regardless of the motion accuracy.

Experimental Results

FIGS. 8-18 show test results of the Telenor encoder codec with and without AMA in a variety of video sequences, resolutions, and frame rates, as described in Table 2. These figures show rate-distortion ("RD") plots for each case. The "Anchor" curve shows RD points from optimized H.263+ (FIGS. 8 and 9 only). The "Telenor 1/2+b" curve shows Telenor with 1/2-pel vectors and bilinear interpolation (the "classical case"). The "Telenor 1/3" curve shows the current Telenor proposal (the "Telenor encoder"). The "Telenor+AMA+c" curve shows the Telenor encoder with the full-search strategy of the present invention. The "Telenor+FSAMA+c", as shown in FIGS. 15-17, shows the current Telenor encoder with the fast-search strategy. (Unless otherwise specified, the full-search version of AMA was the encoder strategy used in the experiments.) All of the test results were cross-checked at the encoder and decoder. These results show that with AMA the gains in peak signal-to-noise ratio ("PSNR") can be as high as 1 dB over H26L, and even higher over the classical case.

Video sequence	FIG. #	Resolution	Frame rate
Container	FIG. 8	QCIF	10
News	FIG. 9	QCIF	10
Mobile	FIG. 10	QCIF	10

	FIG. 11	SIF	15
Garden	FIG. 12	QCIF	15
Tempete	FIG. 13	SIF	15
	FIG. 14	QCIF	15
Paris Shaked	FIG. 15	QCIF	10

Table 2. Description of the Experiments

The video sequences are commonly used by the video coding community, except for "Paris Shaked." The latter is a synthetic sequence obtained by shifting the well-known sequence "Paris" by a motion vector whose X and Y components take a random value within $[-1,1]$. This synthetic sequence simulates small movements caused by a hand-held camera in a typical video phone scene.

Comparison Of Full-Search And Fast-Search AMA

The experimental results shown in FIGS. 16 and 17 demonstrate that the encoder performance with fast-search ("Telenor FSAMA+c") and full-search ("Telenor AMA+c") strategies for AMA is practically the same. This is true because the fast-search strategies exploit the convexity of the RD cost curve in the sub-pixel velocity space. In other words, since the shape of the RD cost follows a smooth convex curve, its minimum should be easy to find with some smart fast-search schemes that descend down the curve.

Combining AMA And Multiple Reference Frames

In the plot shown in FIG. 18, the curves labeled "1r" used only one reference frame for the motion compensation, so these curves are the same as those presented in FIG. 10. The curves labeled "5r" used five reference frames.

The experiments show that the gains with AMA add to those obtained using multiple reference frames. The gain from AMA in the one-reference case can be measured by comparing the green and pink curves, and the gain in the five-reference case can be measured between the blue and red curves.

It should be noted that the present invention may be implemented at the frame level so that different frames could use different motion accuracies, but within a frame all motion vectors would use the same accuracy. Preferably in this embodiment the motion vector accuracy would then be signaled only once at the frame layer. Experiments have shown that using the best, fixed motion accuracy for the whole frame should also produce compression gains as those presented here for the macroblock-adaptive case.

In another frame-based embodiment the encoder could do motion compensation on the entire frame with the different vector accuracies and then select the best accuracy according to the RD criteria. This approach is not suitable for pipeline, one-pass encoders, but it could be appropriate for software-based or more complex encoders. Still another frame-based embodiment the encoder could use previous statistics and/or formulas to predict what will be the best accuracy for a given frame (e.g., the formulas in set forth in the Ribas work or a variation thereof can be used). This approach would be well-suited for one-pass encoders, although the performance gains would depend on the precision of the formulas used for the prediction.

The terms and expressions which have been employed in the foregoing specification are used therein as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions, of excluding equivalents of the features shown and described or portions thereof, it being recognized that the scope of the invention is defined and limited only by the claims that follow.

4. Brief Description of Drawings

FIG. 1 is a diagram of an exemplary full-pel and 1/3-pel locations in velocity space.

FIG. 2 is a flowchart illustrating a prior art method for estimating the best motion vector.

FIG. 3 is a diagram of an exemplary location of motion vector candidates for full-search in sub-pixel velocity space.

FIG. 4 is a flowchart illustrating a full-search preferred embodiment of the method for estimating the best motion vector of the present invention.

FIG. 5 is a diagram of an exemplary location of motion vector candidates for fast-search in sub-pixel velocity space.

FIG. 6 is a flowchart illustrating a fast-search preferred embodiment of the method for estimating the best motion vector of the present invention.

FIG. 7 is a detail flowchart illustrating an alternate preferred embodiment of step 114 of FIG. 6.

FIG. 8 is a graphical representation of experimental performance results of the Telenor encoder with and without AMA in the "Container" video sequence, with QCIF resolution, and at the frame rate of 10 frames per second.

FIG. 9 is a graphical representation of experimental performance results of the Telenor encoder with and without AMA in the "News" video sequence, with QCIF resolution, and at the frame rate of 10 frames per second.

FIG. 10 is a graphical representation of experimental performance results of the Telenor encoder with and without AMA in the "Mobile" video sequence, with QCIF resolution, and at the frame rate of 10 frames per second.

FIG. 11 is a graphical representation of experimental performance results of the Telenor encoder with and without AMA in the "Garden" video sequence, with SIF resolution, and at the frame rate of 15 frames per second.

FIG. 12 is a graphical representation of experimental performance results of the Telenor encoder with and without AMA in the "Garden" video sequence, with QCIF resolution, and at the frame rate of 15 frames per second.

FIG. 13 is a graphical representation of experimental performance results of the Telenor encoder with and without AMA in the "Tempete" video sequence, with SIF resolution, and at the frame rate of 15 frames per second.

FIG. 14 is a graphical representation of experimental performance results of the Telenor encoder with and without AMA in the "Tempete" video sequence, with QCIF resolution, and at the frame rate of 15 frames per second.

FIG. 15 is a graphical representation of experimental performance results

of the Telenor encoder with and without AMA in the "Paris shaken" video sequence, with QCIF resolution, and at the frame rate of 10 frames per second.

FIG. 16 is a graphical representation of experimental performance results of fast-search ("Telenor FSAMA+c") and full-search ("Telenor AMA+c") strategies in the "Mobile" video sequence, with QCIF resolution, and at the frame rate of 10 frames per second.

FIG. 17 is a graphical representation of experimental performance results of fast-search ("Telenor FSAMA+c") and full-search ("Telenor AMA+c") strategies in the "Container" video sequence, with QCIF resolution, and at the frame rate of 10 frames per second.

FIG. 18 is a graphical representation of experimental performance results of tests using only one reference frame for motion compensation as compared to tests using multiple reference frames for motion compensation the in the "Mobile" video sequence, with QCIF resolution, and at the frame rate of 10 frames per second.

FIG.1

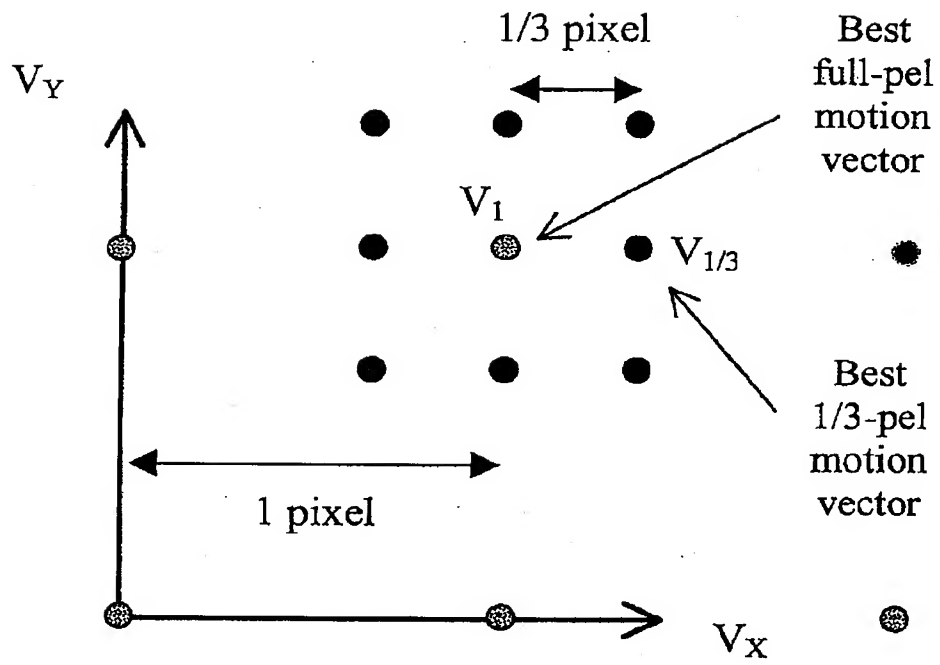


FIG.2

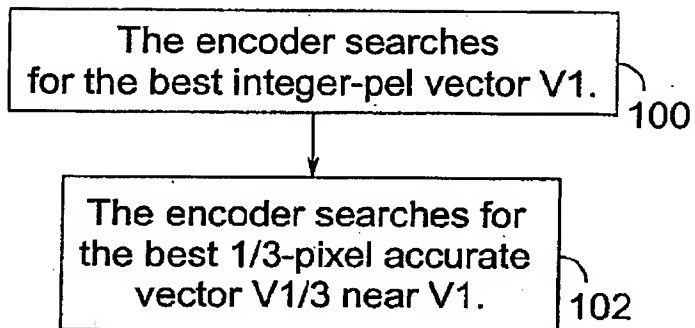


FIG.3

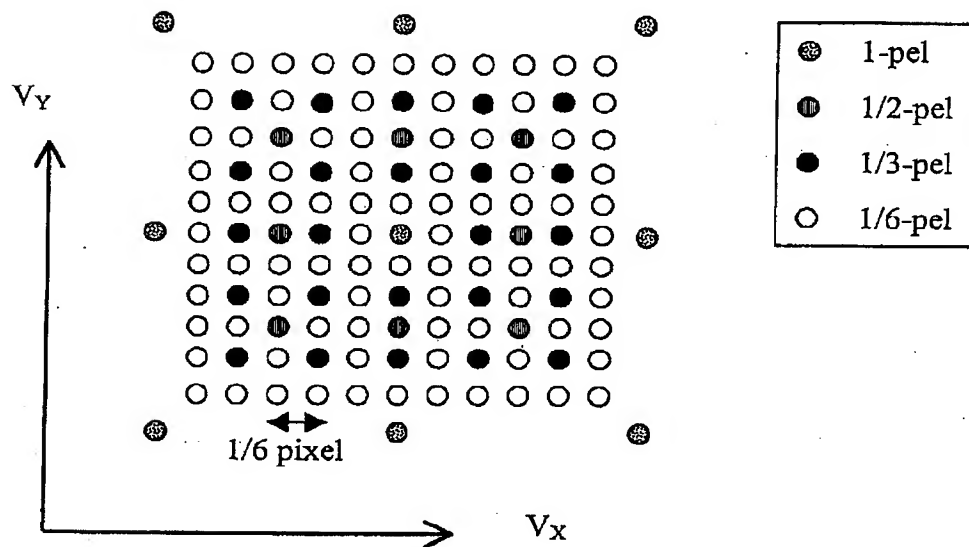


FIG.4

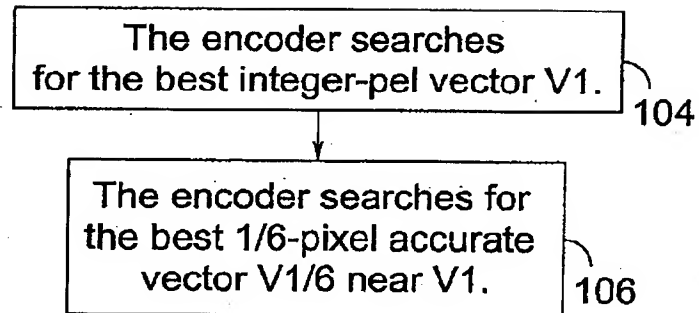


FIG.5

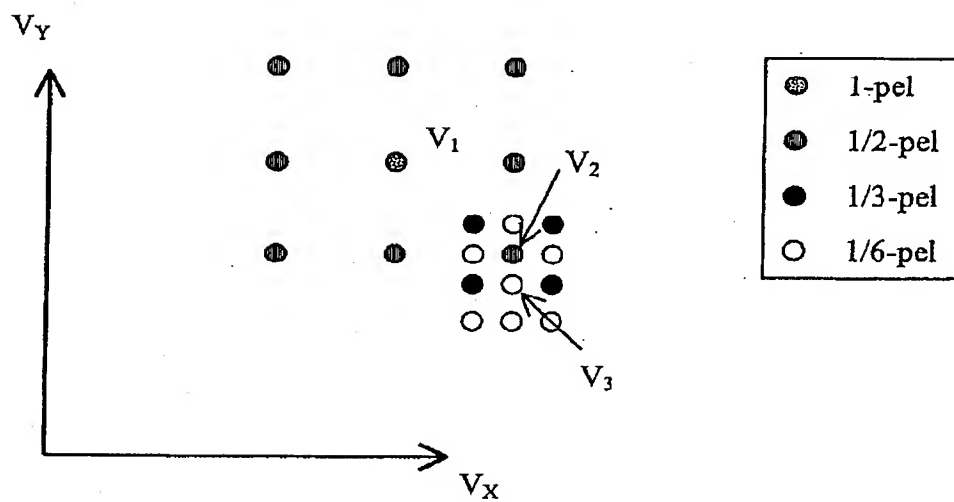


FIG.6

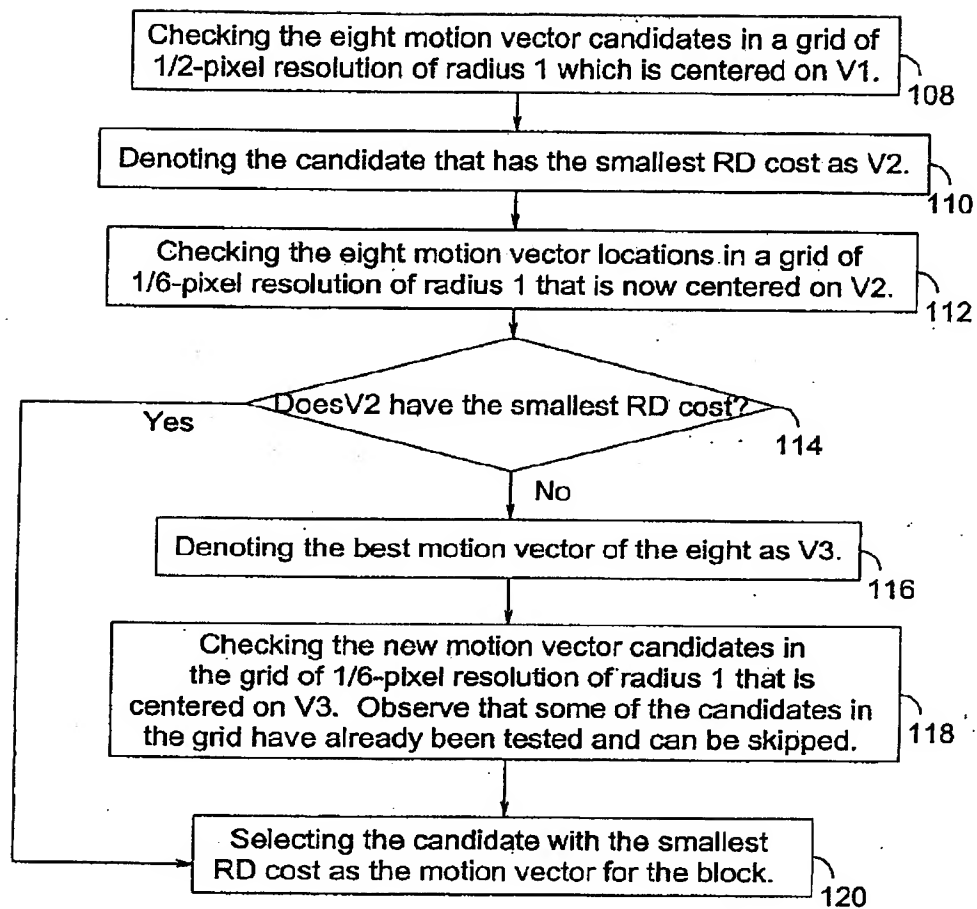


FIG.7

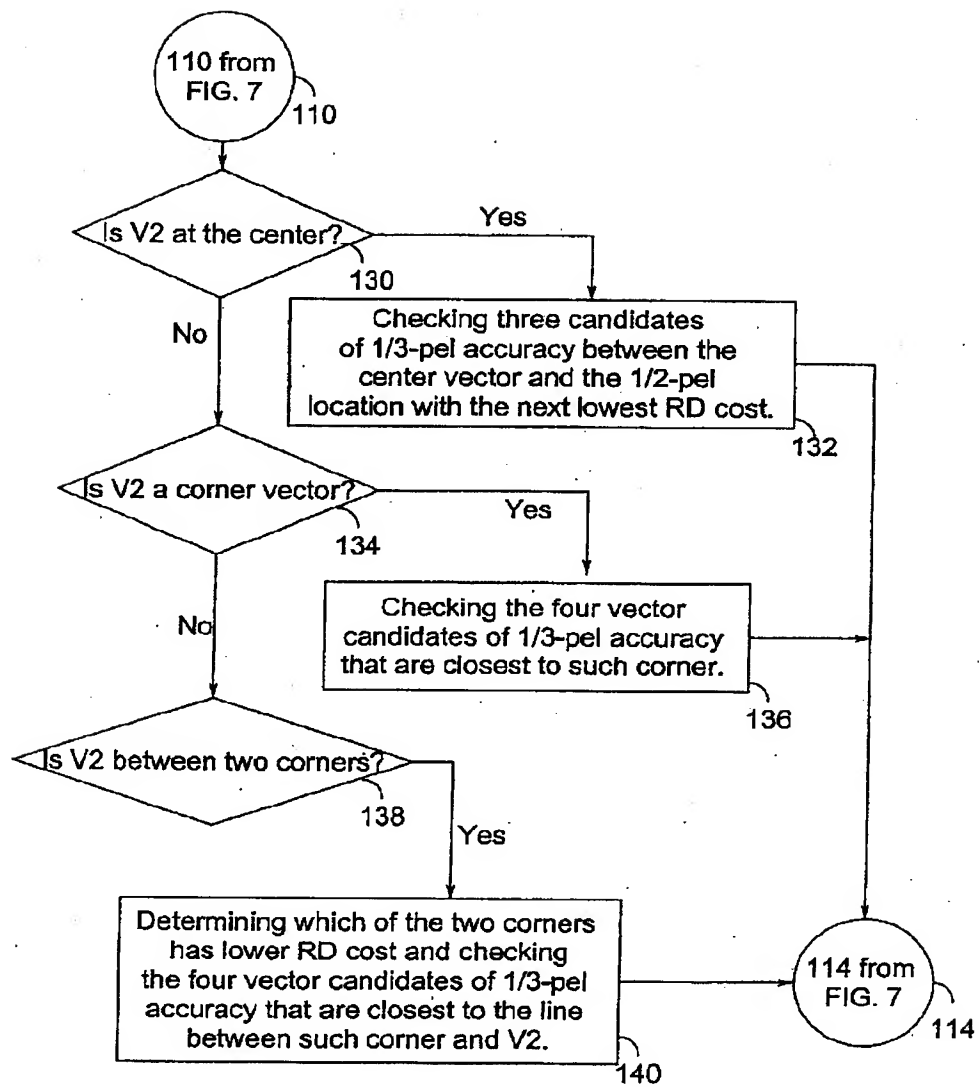


FIG.8

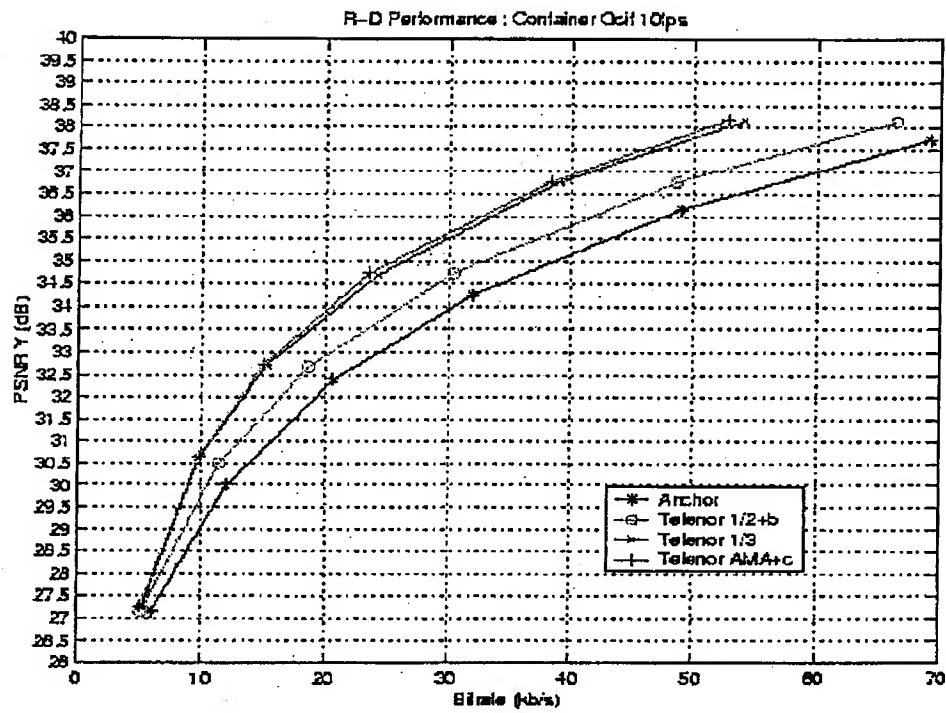


FIG.9

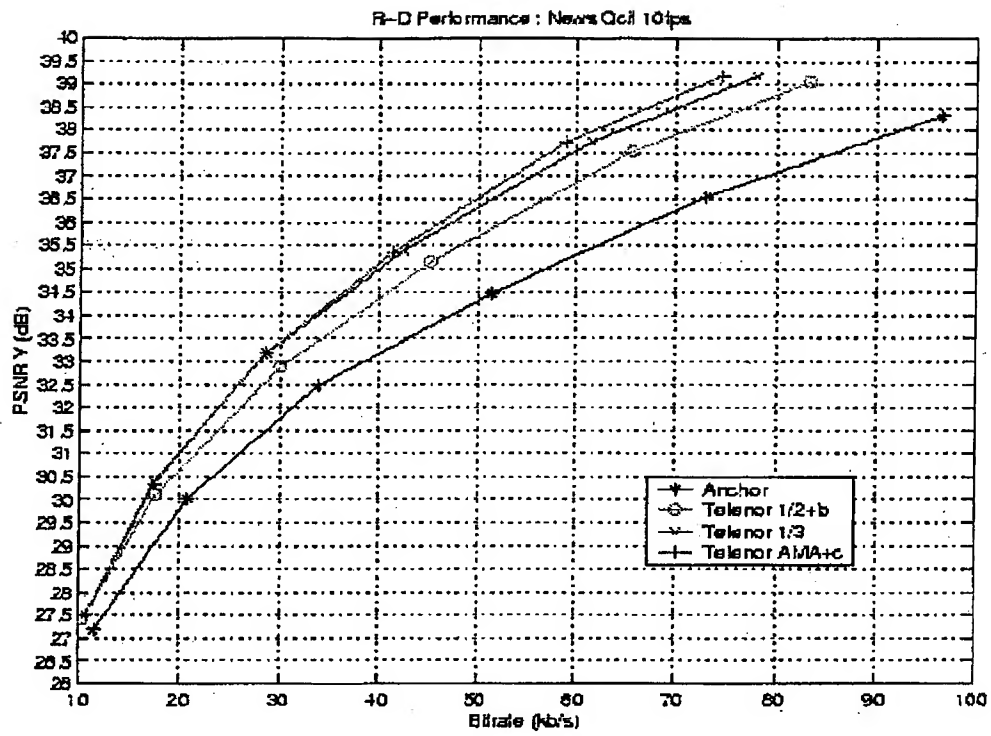


FIG.10

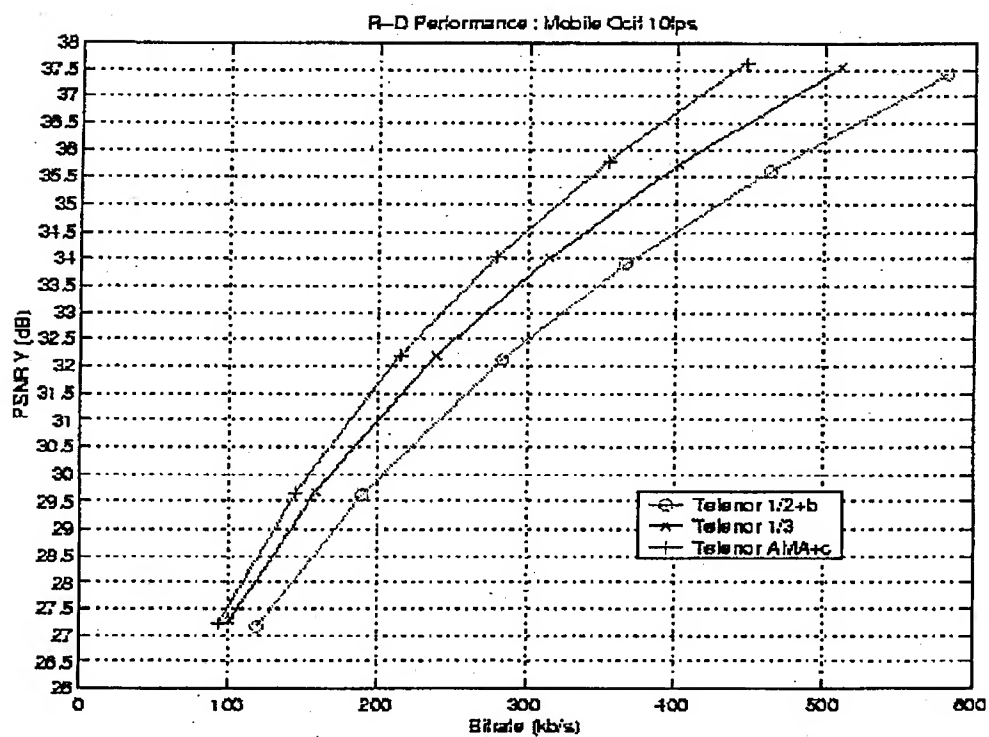


FIG.11

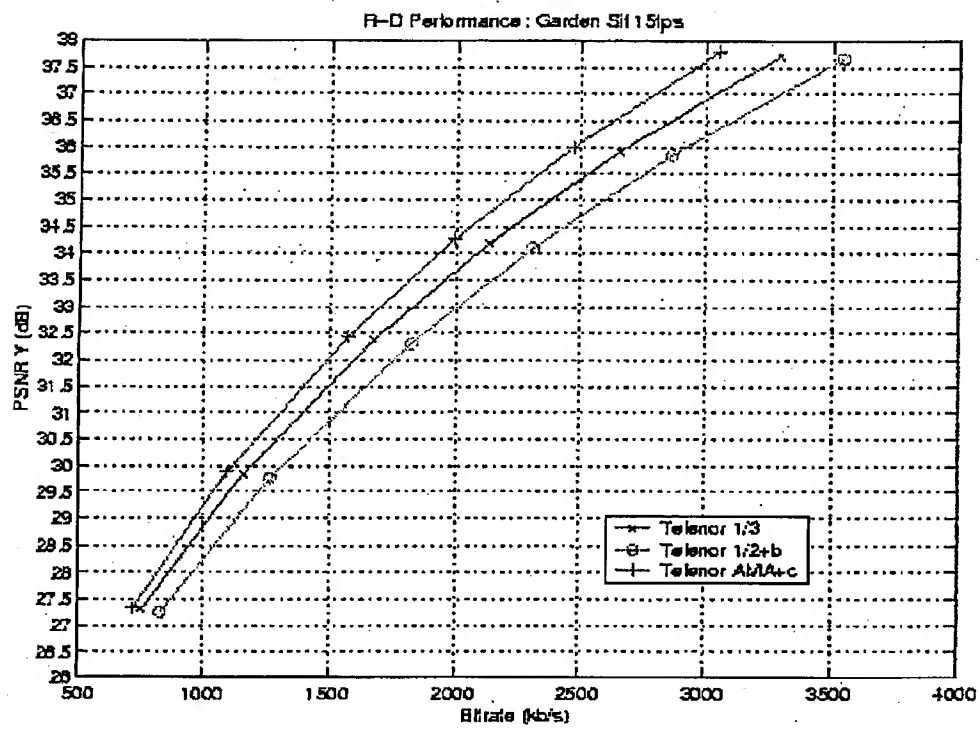


FIG.12

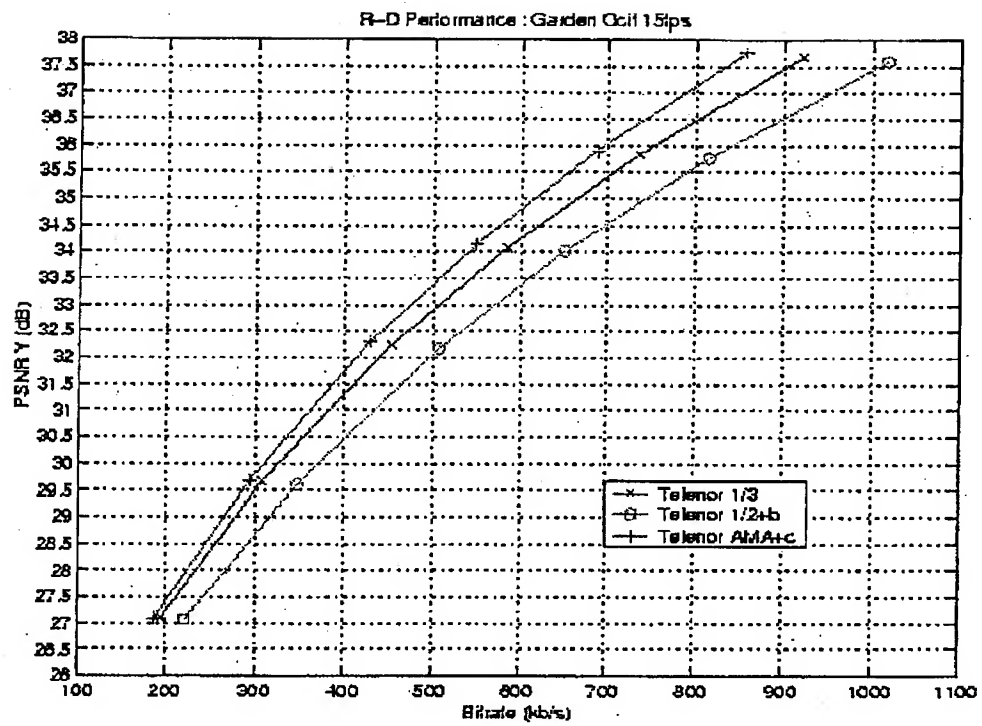


FIG.13

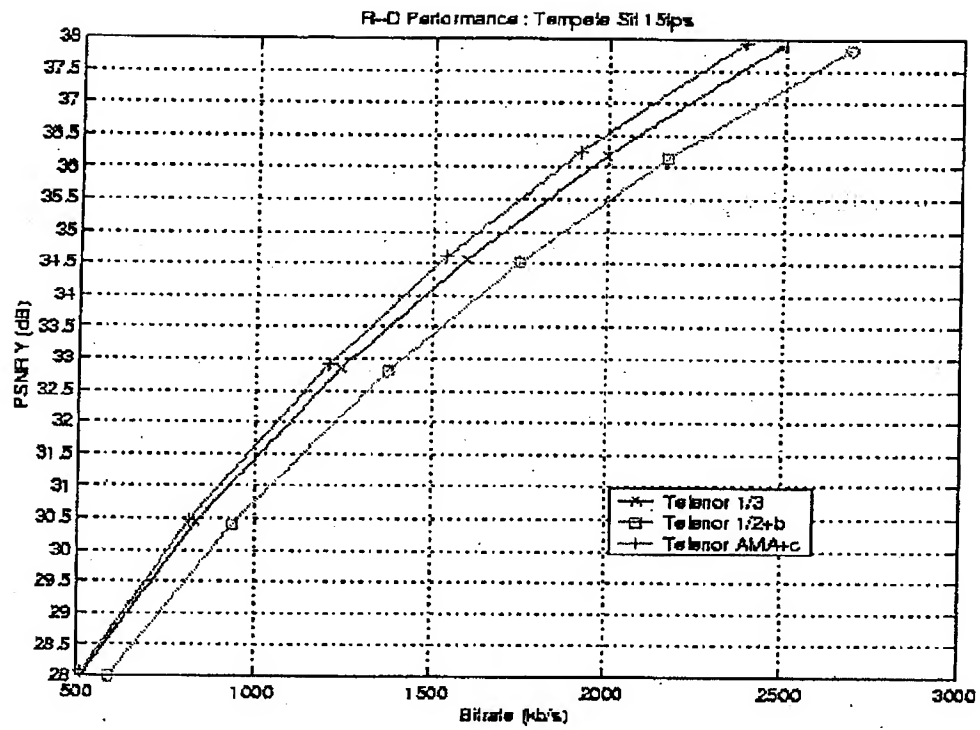


FIG.14

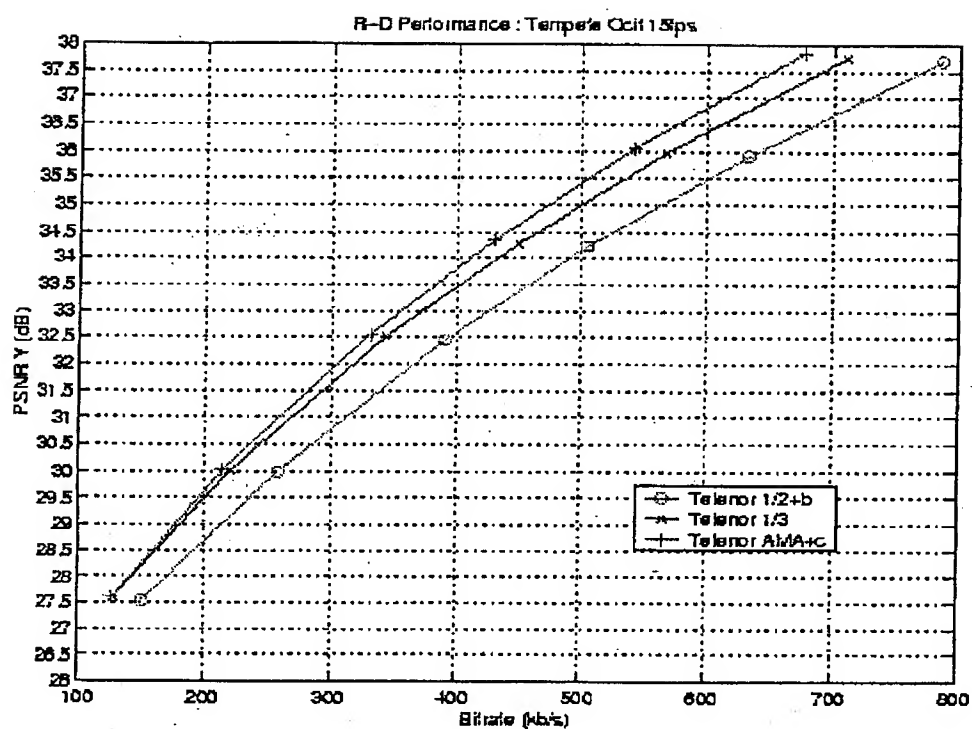


FIG.15

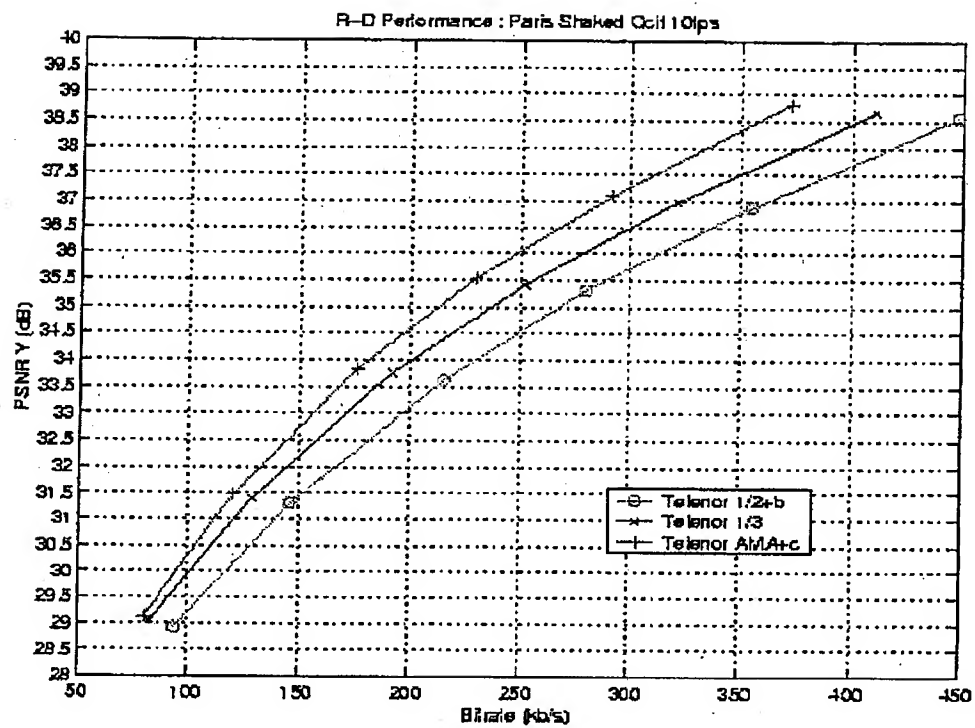


FIG.16

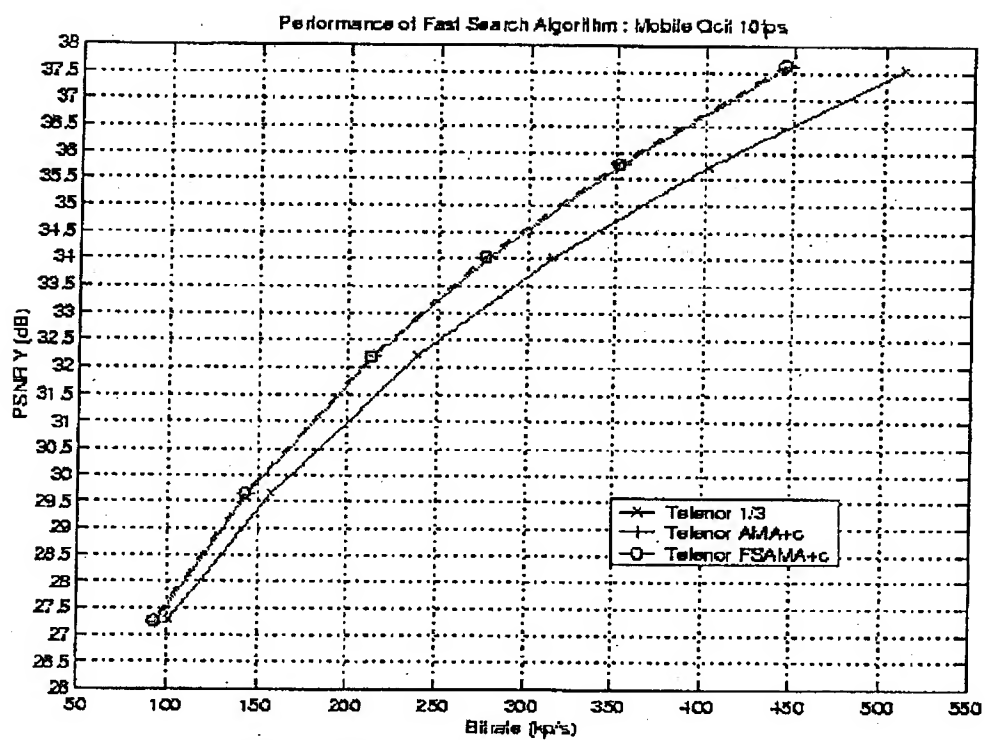


FIG.17

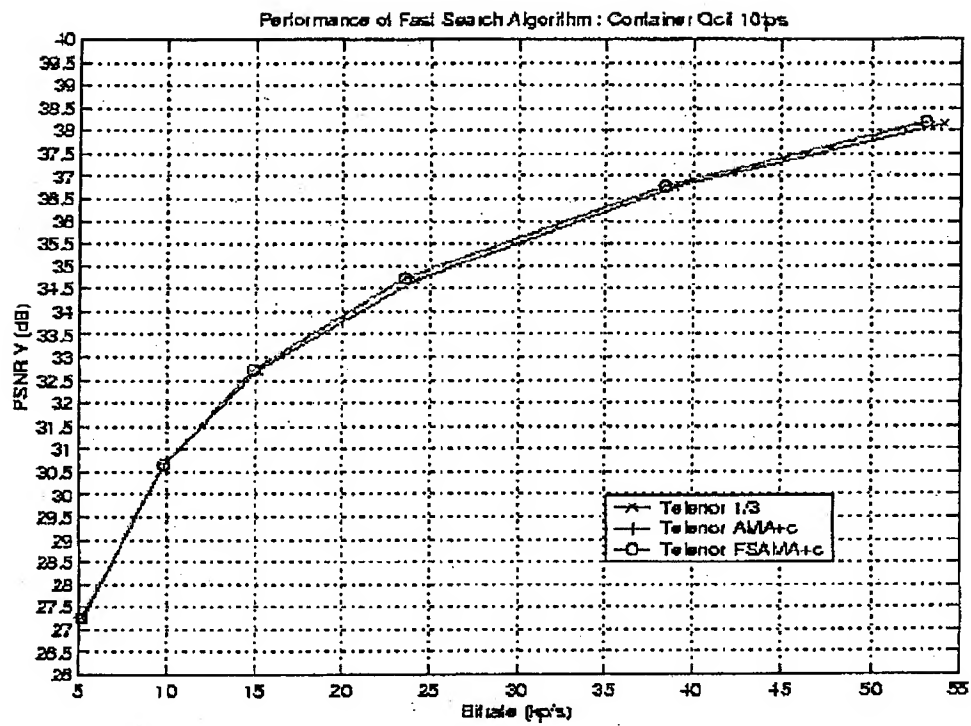
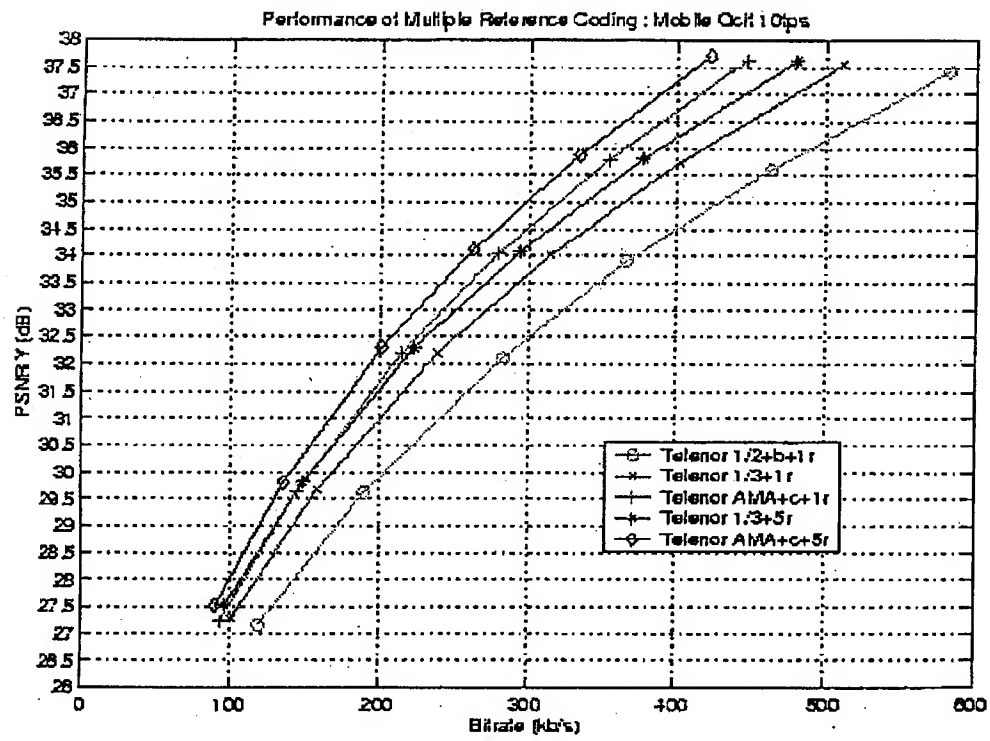


FIG.18



1. Abstract

Methods for motion estimation with adaptive motion accuracy of the present invention include several techniques for computing motion vectors of high pixel accuracy with a minor increase in computation. One technique uses fast-search strategies in sub-pixel space that smartly searches for the best motion vectors. An alternate technique estimates high-accurate motion vectors using different interpolation filters at different stages in order to reduce computational complexity. Yet another technique uses rate-distortion criteria that adapts according to the different motion accuracies to determine both the best motion vectors and the best motion accuracies. Still another technique uses a VLC table that is interpreted differently at different coding units, according to the associated motion vector accuracy.

2. Representative Drawing

Fig.6